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EXPERIENCES WITH THE MERCURY BOILER AND TURBINE.*

BY

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Ever since the use of steam as a source of power began to release industry from its dependence on local water powers, investors and scientists have devoted their efforts to increasing the efficiency both of its application and of its production. The fundamental thermodynamic equation of thermal efficiency $\frac{T_1 - T_2}{T_1}$ has been constantly before their eyes and has spurred them on to push T_1 and T_2 further and further apart, sometimes by raising T_1 and sometimes by reducing T_2.

Long ago perfection in condensing practice brought T_2 down to nearly the theoretical absolute minimum of the vaporizing point of water in a perfect vacuum and, therefore, recent efforts toward improved efficiencies have been directed toward the raising of the initial temperature T_1. Unfortunately, every increase in the temperature of steam or gas is accompanied by an increase in pressure so that the applications of increased temperatures have been unable to proceed at any faster rate than improvements in pressure resisting materials and construction could be accomplished.

The lines of principal endeavor in the last fifty years toward a larger T_1 have been in the development of the gas

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engine, the gradual increase in the temperature and pressure of so-called low pressure steam up to 400–600 pounds, and in the development of high pressure boilers and turbines which carry the temperatures up to the higher limits imposed by pressures of 1,200–1,400 pounds. Experimental work is also being carried out on steam at still higher pressures.

The problems of the safe handling of steam under such pressures at temperatures where steel becomes red hot are of the greatest magnitude both as regards safety, cost and maintenance, and to those who have partially solved these problems is due the great credit.

Fortunately, nature has provided that different substances shall have different vaporizing points and it is the characteristic of mercury to vaporize at a very high temperature as compared to water which so appealed to Mr. W. L. R. Emmet that for the past twenty years he has devoted himself to using this fact to obtain a very high figure for T_1 without the attendant disadvantage of high pressure. While water vaporizes at 212° under atmospheric pressure mercury under the same condition does not vaporize until 675°; and at a temperature where steel becomes visibly red, the corresponding pressure which has to be handled in piping, valves, turbines, etc. is less than 150 pounds with mercury vapor instead of being ten times this figure as is the case with steam.

But I do not propose in my address tonight to be technical nor even scientific. The thought I had in mind when I accepted the very kind invitation of the Franklin Institute was that it would be an opportunity to pay a much deserved tribute to the ability, faith and perseverance of a few of the men who, in spite of almost insurmountable difficulties, of heart breaking disappointments, and of apparent failures carried on; and who have given mankind a practical solution for the problem of high initial temperatures and thus made possible a very large future conservation of the world's fuel resources.

Many men have contributed to the work,—engineers, scientists and skilled workmen, but it is the following six men to whom I wish to direct my tribute tonight:

First of all to Mr. W. L. R. Emmet, engineer of the General Electric Company, scientist and inventor. His

brilliant mind originated the undertaking and his tireless energy has carried it through in spite of all difficulties.

To Messrs. Coulson, Hackett and Sheldon, engineers of the General Electric Company, in charge of the detail, design and actual construction and installation.

Ingenuity in overcoming difficulties on the job and well-reasoned conclusions drawn from careful observation of phenomena involving both operating and non-operating conditions were some of their essential contributions.

To Mr. T. H. Soren, Vice President of The Hartford Electric Light Company, whose clear engineering insight was able to determine that, what often appeared to be absolute failure was in fact due to inconsequential defects, and thus to carry on under experiences which would ordinarily have caused the abandonment of the undertaking.

To Mr. James Orr, Superintendent of Power of The Hartford Electric Light Company, who for ten years has had his power houses turned into experimental laboratories and who, by close attention to the experimental efforts, could point the way to the essentials required for a practical installation.

I do not propose to mention these men or their work individually but I propose, with the help of illustrations, to tell the story of ten years of intensified research on a commercial scale that has been devoted to the perfection of the process.

Many engineers not conversant with the detail of the development, have come to the conclusion that there must be something fundamentally wrong with a process that after so many years of intensive work is not yet in general use. They forget that the development had to go along step by step; each fault in workmanship or design had to be diagnosed and corrected one after the other. Sometimes the changes required only days to accomplish but sometimes weeks and months were involved and, on three occasions, the rebuilding required substantially a year each time, and of course during each shutdown no experience could be acquired. The length of time is, therefore, not surprising and in no way should it cause engineers to have doubts as to the eventual general use of the process.

Naturally the end of the development has not yet arrived. The very fact of curing so many unforseen difficulties has added to the complexity as was also the case in the development of the automobile which after many years of accumulation of safe-guards and gadgets of all kinds has in the process of re-design become most desirably simple. So too in the case of the mercury must the difficulties which have so far been overcome by additions and complexities be eventually eliminated through simplification of design. Today efficiency and reliability have been achieved but there is still much to be desired as to possibility of inspection and ease of ordinary tube cleaning. No one objects to cleaning tubes occasionally so it would seem more logical to make a design which permitted easy cleaning rather than to insist so early in the game on the ultimate perfection of a boiler that never would need cleaning.

Tonight with the help of slides, I propose very hurriedly to carry you through ten years of development work and then say a few words as to the operation of our present plant—its efficiency and reliability records together with method of operation and a description of the mercury cycle.

The first experiment made by Mr. Emmet was at the Schenectady Works of the General Electric Company in 1912. This first boiler consisted of a piece of pipe 24″ long by 1″ in diameter having another piece of pipe 4″ in diameter welded to the top of it to act as a vapor drum. Inside the 1″ pipe was inserted a core, that permitted a flow of liquid down through its center which had angular spaces on the outside through which the heated liquid rose between the outside of the core and the inside of the tube as heat was applied to the outside of the tube. Since that time experimental work on the process has been going on continually in Schenectady.

FIRST INSTALLATION.

Our experience dates from 1922 when work on the first installation of a unit intended for commercial generation of electrical energy was begun at the Dutch Point plant of The Hartford Electric Light Company of Hartford, Connecticut. The executives of the Hartford Company entered into the agreement for this first unit with the full knowledge that it could not be considered anything more than an experi-

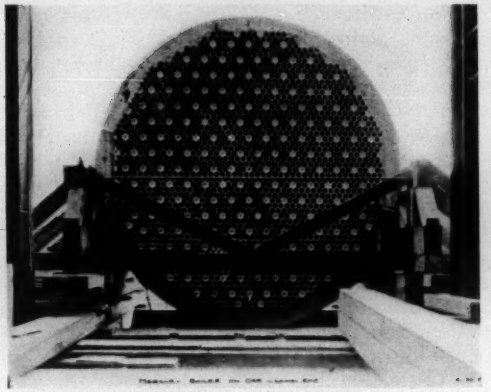
ment for a considerable period. However, there was enough proven data available at Schenectady, obtained over the first ten-year period of experimental work, to justify the necessary expenditures for proving, on a commercial operating basis, the economic possibilities of this binary cycle. The officers of the Light Company were prepared from the very beginning to accept many setbacks and the usual criticisms all pioneers are subjected to when making any departure from the well beaten tract.

In view of its experimental nature the unit at Dutch Point was installed in a small, inexpensive building attached to one side of the boiler house. Construction work was begun in 1922 and pressure was raised on the mercury boiler for the first time on September 6, 1923, and on September 7, while attending a session of the New England Section of the National Electric Light Association devoted to the problems of power production, I received a telegram informing me that for the first time in history electricity produced by the use of a mercury turbine had gone out over the lines of our system and into the homes and offices of our customers. On that occasion, I stated that only time could tell whether the message commemorated an epoch or a dud but even my expectations of trouble to come did not visualize the length of time before regular and reliable operation would be attained.

ORIGINAL HONEYCOMB MERCURY BOILER.

The mercury boiler was unlike anything of that nature previously built. It was of the fire-tube type and had the appearance of a honeycomb in which the center cell out of every group of seven had been sealed over; this one acted as a down tube for the six tubes surrounding it. The boiler was 12′ 8″ in outside diameter and 4′ 7½″ high and was built up of hexagonal tubes welded along the edges of the adjacent tubes. This first type of boiler was not eventually a success because it did not lend itself well to caring for expansion and contraction strains nor to cleaning and it was later replaced by one of a water tube principle following the same general characteristics as the single tube on which Mr. Emmet made his first experiments.

FIG. 1.



Mercury boiler, bottom view, unloading.

THE PRINCIPAL OTHER PARTS OF THE INSTALLATION ARE SHOWN IN THE FOLLOWING ILLUSTRATIONS.

Figure 2 shows the opening leading into the condenser-boiler to which is welded the shell of the Mercury Turbine. The water tubes shown have the dual function of first condensing the mercury vapor after it has passed the wheel and second by the absorption of the latent heat of evaporation to convert the condensing water into steam which is used to produce additional power in the regular steam turbines of the plant. An interesting anomaly, in passing, is the fact that the condensing water here used is pre-heated.

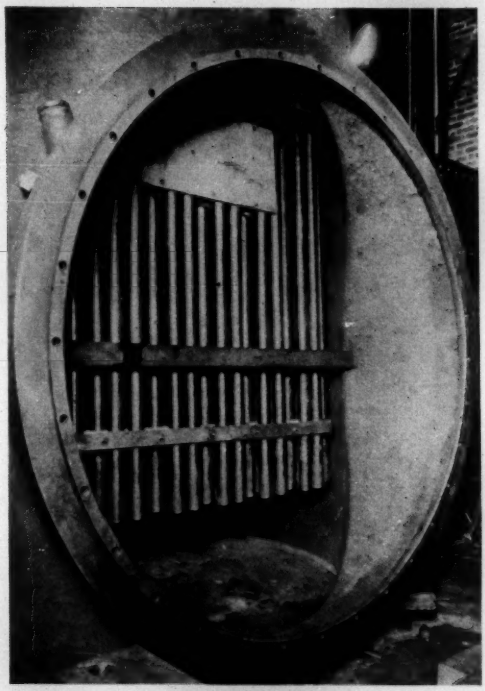
Figure 3 shows the turbine and generator about to be attached to the opening in the condenser boiler.

Figure 4 shows the main vapor pipes leading from the boiler to the turbine before the lagging has been applied; also the valves for by-passing the vapor into the condenser, used to stop or start the turbine; also one of the accordion expansion joints can be clearly seen.

Figure 5 shows the first mercury unit completely assembled.

Figure 6 shows the operating record of the set from September 7th to the end of the year. Each gap in the

FIG. 2.



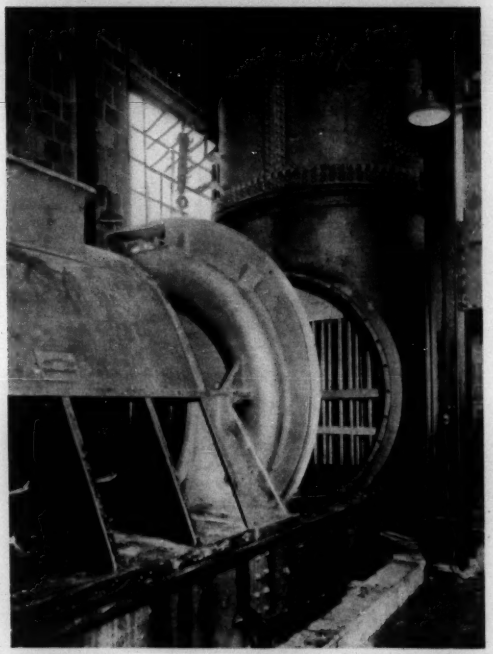
Mercury condenser boiler.

record on this and on the following similar illustrations indicates a shutdown either for inspection or for some difficulty or to solve some problem and the time it took to make the change is indicated by the duration of the gap.

In this connection it is only fair to say that very many of the gaps were caused by troubles that had no connection with the mercury process but which, none the less, consumed time and money.

The first long shutdown from September to November was due to the necessity of rebucketing a wheel of the turbine

FIG. 3.

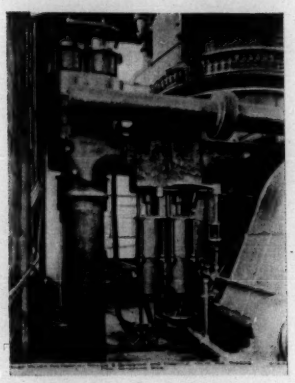


Turbo-generator and condenser boiler, open view.

after the buckets had been damaged; the cause of this damage was a purely mechanical failure in a valve, the broken portion of which went through into the turbine. In fact the only shutdown attributable to the process during the year, was to reweld a small leak in the mercury pre-heater.

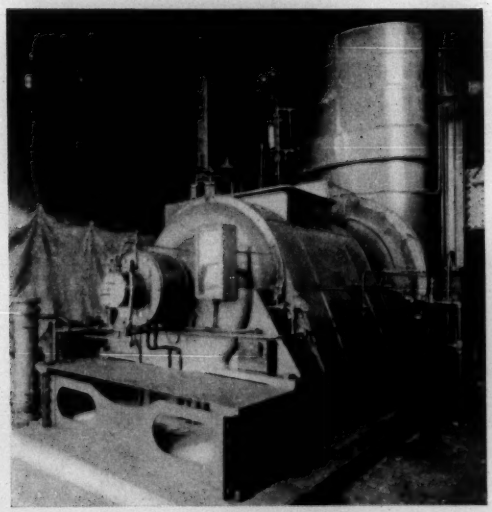
In connection with the more or less discouraging shutdowns in this and the succeeding years, it was of great interest to turn back to the initial record of the first Parsons turbine used in this country. This pioneer installation was also made in the power house of the Hartford Company.

FIG. 4.



Relief governor and throttle valves from generator side.

FIG. 5.



Mercury turbo-generator set with condenser boiler.

FIG. 6.

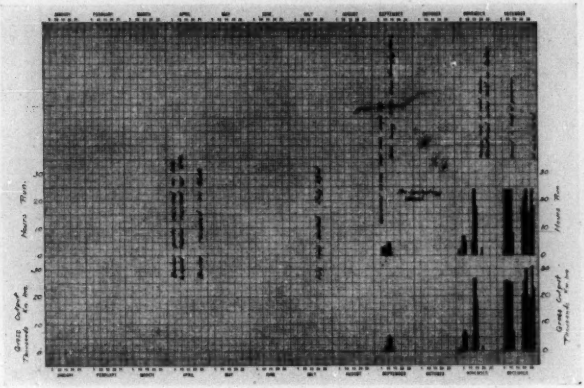


Chart of generator output and running hours for year 1923.

FIG. 7.

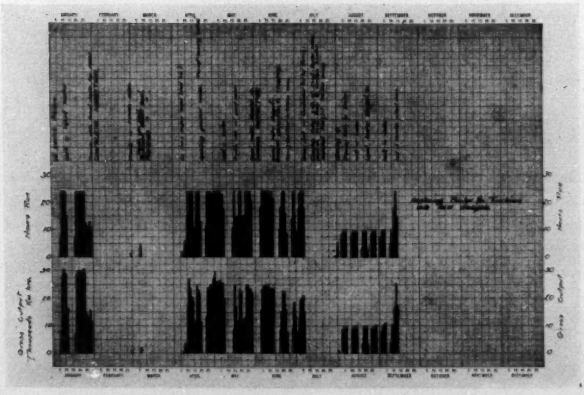


Chart of generator output and running hours for year 1924.

Its record showed that it was in operating condition only 589 hours of the first fourteen months of service and in that time generated only 500,000 kwhrs. The fact that, in spite of troubles, the mercury installation in its first four months had equalled this fourteen months record both as to "hours available" and "kwhrs generated" was of great psychological assistance to those who were laboring with a succession of new problems embracing all phases of design, construction and operation.

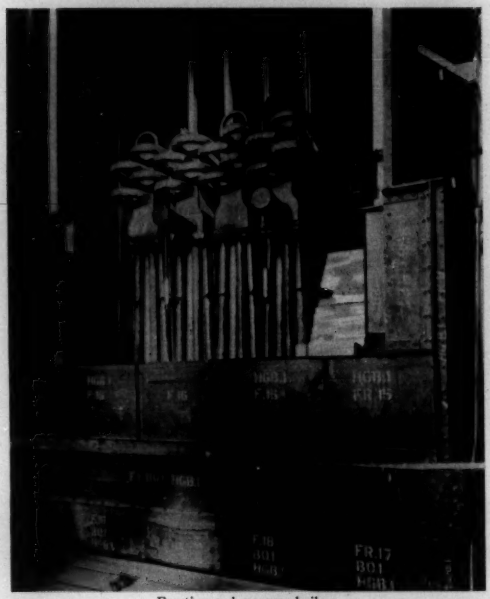
Figure 7 is a similar chart for 1924. The most noticeable thing about this chart is the number of mercury leaks recorded. Whenever the boiler was inspected minute leaks were discovered and probably there were more constantly present during operation than was at that time realized as up to that time the present very sensitive instrument for the detection of mercury vapor in the flue gas had not been invented. It was the frequency of these leaks that proved the honeycomb type of boiler to be impractical since the very great number of welds on its face were directly exposed to the maximum heat of the furnace. On September 14th, a few days after the anniversary of its start the boiler was permanently withdrawn from service and reconstruction of the plant started to accommodate a new boiler of radically different design.

THE SECOND EXPERIMENTAL MERCURY BOILER.

Figure 8 shows that the new boiler was very different in appearance, being of a porcupine type with each tube welded into a large header and each tube having its own internal circulation system quite independent of any other.

Figure 9 is the 1925 operating record. Fires were lighted in July but even before any load was carried it became obvious that the tubes were defective in their internal design. As a result the plant was disassembled, the boiler section conveyed to the South Meadow Plant where each of the hundreds of tubes were removed from the headers and a new design of cores and circulating passages substituted for the impractical ones with which they had been equipped. As a result of the time required for this change the year recorded only five days of operation and was thus a total loss as far as the acquisition of experience was concerned.

FIG. 8.



Erecting 2nd mercury boiler.

Figure 10 covers the year 1926. Here again major and minor interruption occurred and while the correction of each new fault meant progress, it is obvious that as yet no experience of continuous operation has been obtained. It should be noted that the most frequent repairs were those to the peculiar shaped header which by this time was recognized to be a fundamental error in design though in itself only a detail.

Figure 11 is the story for 1927. In this case, although the chart shows frequent gaps and only ten instead of twenty-four hours use per day, it was really at last continuous operation as the shutdowns in the majority of the cases were voluntary and caused by the seasonal surplus of water the cost

FIG. 9.

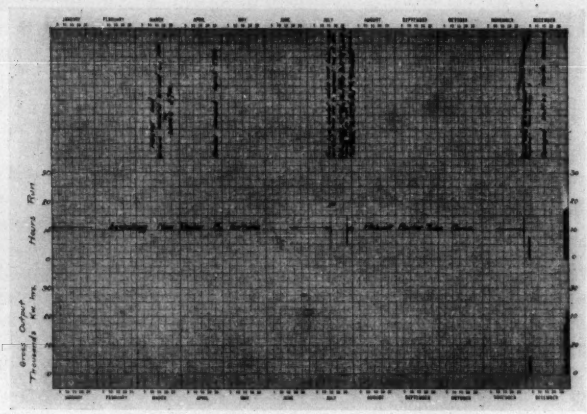


Chart of generator output and running hours for year 1925.

FIG. 10.

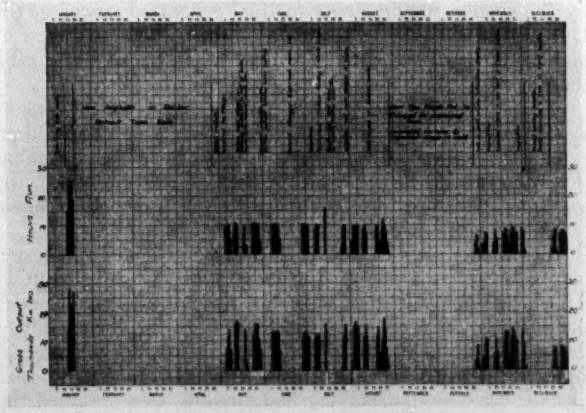


Chart of generator output and running hours for year 1926.

FIG. 11.

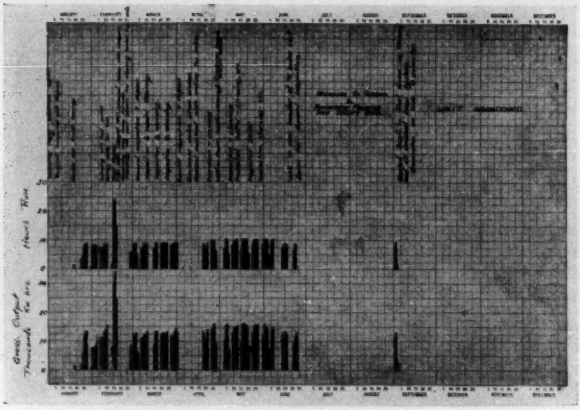


Chart of generator output and running hours for year 1927.

of which not even the efficiency of the mercury process can better. The operation during these months was governed by the system requirements for fuel generated power in the Dutch Point Plant and, as such power was not required at night or over week-ends, the plant was shut down during these hours.

During this period of very satisfactory operation, plans were being perfected for the next step which was to build an extension on the new South Meadow station for the installation of a unit having a generator capacity of 10,000 kw., the combined generator and steam capacity of the boiler being twice this figure or 20,000 kw. plus.

The final run of the experimental plant ended in burned out boiler tubes owing to the fact that a loose ½″ nut in some manner had gotten into the system and lodged under the mercury drain-off valve thus draining the mercury out of the boiler, and the tubes, without the protection of the internal liquid, naturally overheated. Inasmuch as sufficient information for the new undertaking had already been obtained the expense of retubing this unit did not appear to be warranted and the boiler was removed to make room for further experi-

mental work on future refinements and simplification of a radical nature; which work is still in progress and is leading to simplification in design which will undoubtedly appear in the eventual article of general use.

Before continuing further with the history and description of the new equipment, this would be an appropriate place to give a brief outline of the mercury cycle itself.

Figure 12 is diagrammatic. This equipment is oil fired. There are 10 vertical burners at the bottom of the furnace, insuring, as far as possible, equal division of heat over the entire bottom of the boiler.

The gases pass between the tubes and between the 7 drums of the boiler. The boiler drums are lagged to prevent superheat. The gases then pass through the liquid heater or mercury economizer and then through the steam superheater, superheating the steam to approximately 725°. It then changes direction and goes down first through the water economizer and through the air preheater to the bottom of the stack.

The furnace is aircooled. The air passes through the preheater counter-flow to the top of the furnace and then through cast iron hollow blocks down through the furnace walls to the burners.

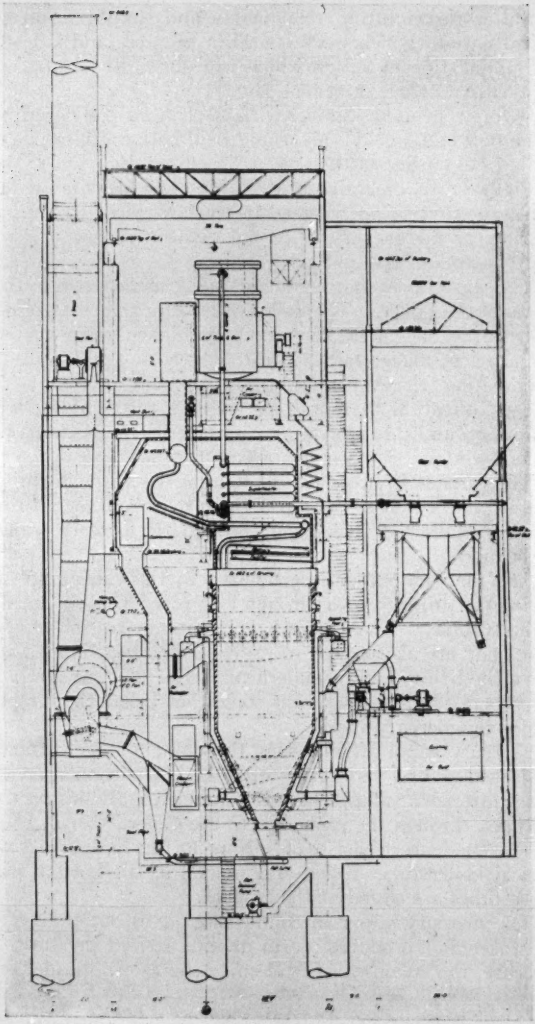
The mercury vapor is generated in the tubes and after leaving the drums passes through long pipes inside of the flues to the turbine. These pipes have a total expansion of about 7". They are also lagged to prevent superheat immediately above the boiler, and de-superheat in the later section of the flue, where the temperature is somewhat below the temperature of the mercury vapor.

Mercury vapor after passing through a 5-stage turbine, is condensed around vertical water tubes in the condenser, then passes through a sump, where any impurities are skimmed off, and back through the preheater to the boiler.

The condenser consists of a drum 12 feet in diameter with vertical boiler tubes rolled and welded in the bottom plate. These tubes are closed at the bottom.

The mercury vapor in condensing, gives out the heat to the water and produces steam at any desired pressure. In this case, the steam can be taken to the 250 lb. header or to

FIG. 12.



Cross-section (white background).

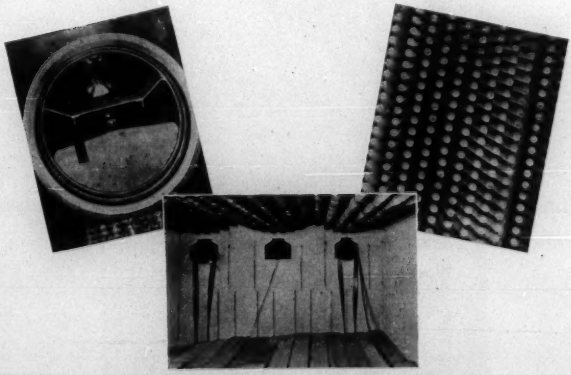
the 450 lb. header, by changing the valves, the only difference being the reduction of the vacuum, to obtain the additional heat required for the higher pressure.

Before the water goes to the condenser, it is preheated in the economizer, and the steam is taken through a superheater and direct to the steam header in the station.

All mercury piping and mercury vapor under pressure is either in the flues or inside of a small chamber surrounding the generator from which air is continuously drawn to the stack. Above the discharge of the ventilating fan, gases are continuously drawn out and impinged on a paper covered with selenium sulphide. In case of leakage of mercury, the paper is turned black.

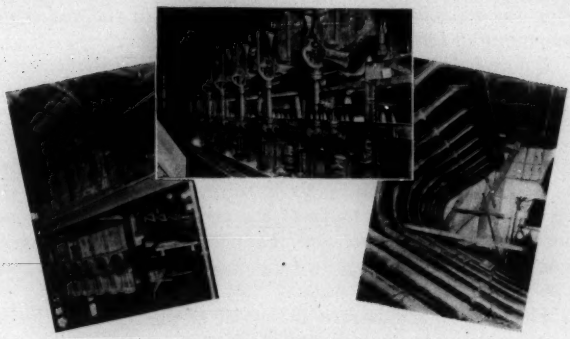
The following illustrations consist of photographs during construction and after completion of various essential features of the present South Meadow Plant Mercury Unit. They need very little comment, other than that given under the photograph.

FIG. 13. FIG. 14. FIG. 15.



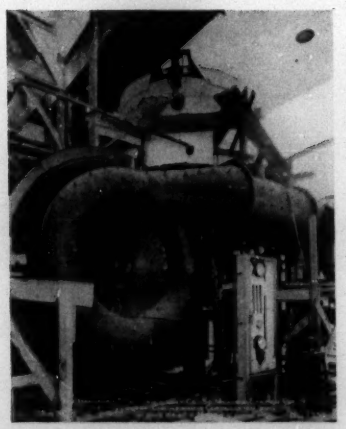
End view of mercury boiler drum showing arrangement.
Mercury tubes after 100 hours run.
Tile back of boiler, explosion doors and truss hangers.

FIG. 16. FIG. 17. FIG. 18.



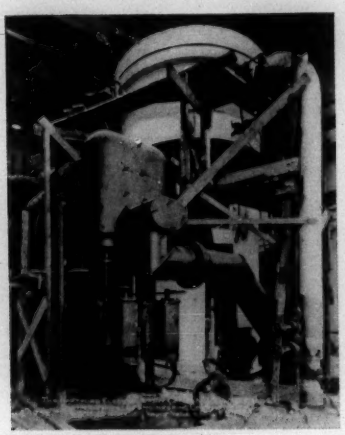
Soot blowers and explosion doors, rear of boiler.
Front of boiler looking northeast.
Mercury pipe bends, welds, baffle.

FIG. 19.



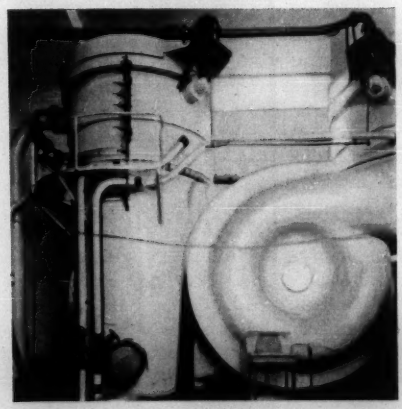
Turbine head and vapor pipe.

FIG. 20.



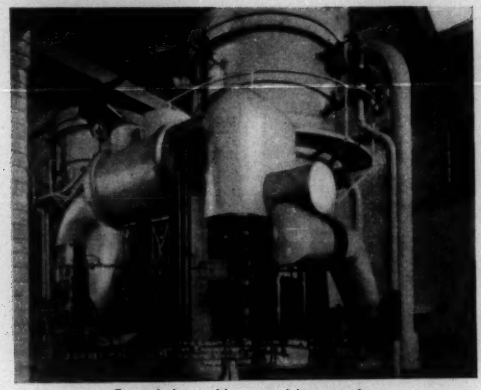
Mercury vapor valve and relief pipe.

FIG. 21.



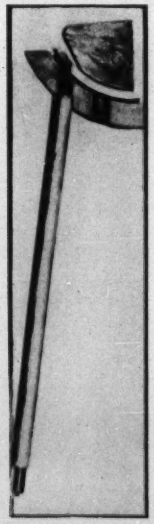
Turbine and south condenser.

FIG. 22.



General view turbine, vaporizing controls.

FIG. 23.



Sectioned generating tube and drum.

1928 OPERATING RECORD.

Figure 24 shows the 1928 operating record. After an interval of fourteen months devoted to the construction of

FIG. 24.

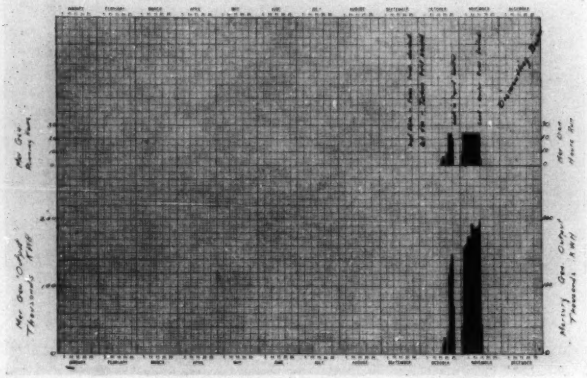


Chart of generator output and running hours for year 1928.

the new large unit and the preparation for its installation all was ready for the start. Naturally minor changes were required at first but by November 1 the unit was assigned the regular service and for the next two weeks the smooth and regular operation left nothing to be desired. All hands were, however, doomed to bitter disappointment as on November 16 a leak developed in a boiler tube and when this was cut out for examination the fact was disclosed that it had become overheated, due to a defective nipple in the top of the down-coming tube. This nipple was too loose and allowed vapor to shut off the down-coming liquid and starve the tube.

There was nothing for it but a new design and a reconstruction of the cores of the 3,080 tubes. Owing to the necessity for the assembly of the cores with the tubes in place, a makeshift construction was adopted in which the cores were made in four sections. Later experience emphasized the old saying that it would have been better to "make haste slowly."

1929 OPERATING RECORD.

Figure 25 shows the 1929 operating record. The before described re-design used up eight months and it was not until

FIG. 25.

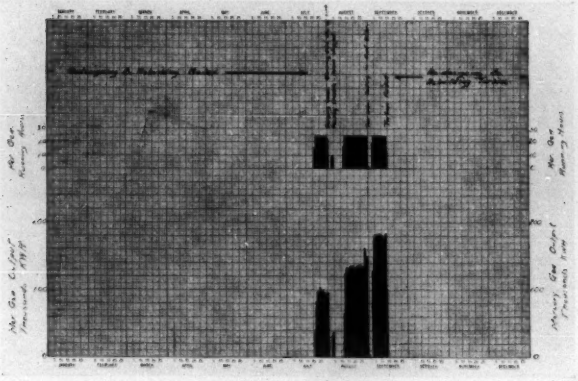


Chart of generator output and running hours for year 1929.

July that again all was set to go—another long period wherein no experience was acquired.

The operation, although not quite continuous due to shut-downs for the purpose of extra careful inspections, was very satisfactory and for two months the unit was regularly operated on a twenty-four hour basis, but on September 15 the turbine began to vibrate badly and was shut down.

When opened up it was found that the second stage diaphragm had distorted and was rubbing on the first stage wheel. The only answer was the removal, re-design and re-building of the wheels and diaphragms—another long shut-down which was particularly distressing on account of the fact that it was due to an error in mechanical design, rather than to any problem connected with the mercury cycle.

1930 OPERATING RECORD.

Figure 26 shows the 1930 operating record. This year's operation started in February with the turbine rebuilt and

FIG. 26.

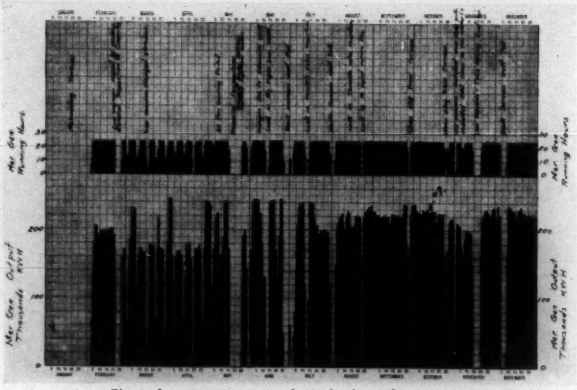


Chart of generator output and running hours for year 1930.

with no change in the boiler, the tubes of which still contained the makeshift core construction.

The unit was operated on a twenty-four hour basis at full load with only such shutdowns as were due to load requirements, inspections and minor repairs to auxiliary apparatus not involved in the mercury cycle proper. This operation gave a wheel output of 52,000,000 kwhrs. for the year at an efficiency of 10,300 B.T.U.'s per kwhr. for the combination of wheel output and condenser-boiler steam. In arriving at this figure for efficiency the usefulness of the steam was figured at the annual average water rate of the station including proportional share of losses in auxiliary apparatus.

1931 OPERATING RECORD.

Figure 27 shows the 1931 operating record. The previous year was the first time the equipment had been given anything like the equivalent of a year's steady use and only now could the effects of such prolonged operation be expected to appear. Sure enough, in February a failure of a boiler tube compelled a shutdown. Upon inspection of the tube, a serious condition was disclosed, as the projections on the loose cores had worn

FIG. 27.

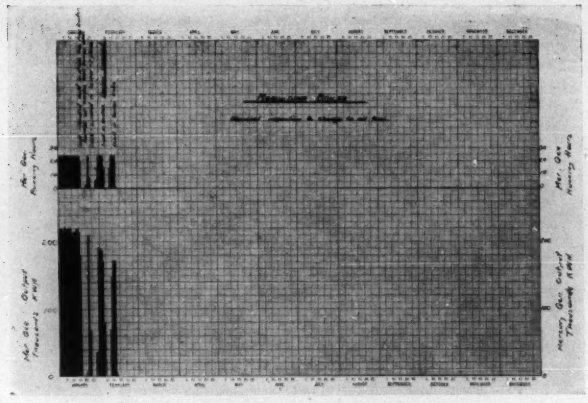


Chart of generator output and running hours for year 1931.

their way through the outer tube. In addition, the various parts of the cores had rubbed and a large amount of ground-up iron was released in the boiler. This apparently accounted for any minor accumulations of iron about the tubes, and it was not appreciated at the time that there is a certain amount of erosion from rapid circulation of the mercury, causing trouble that will be mentioned later.

1932 OPERATING RECORD.

Figure 28 shows the 1932 operating record. March, 1932 saw the retubed boiler again in regular service which was carried through the year—the only shutdowns, except for one small leak in a pipe weld being for inspection and the occasional cleaning out of the tubes of the mercury preheater. The need for this cleaning arose from the use of an oil protection against rust, during shipment, on the interior of the boiler tubes. This oil was supposed to vaporize when the tubes were put in service, but instead it carbonized, causing trouble both at this time and later. The amount of load carried from day to day was governed, spring and fall, by the amounts of surplus water power available in that year.

FIG. 28.

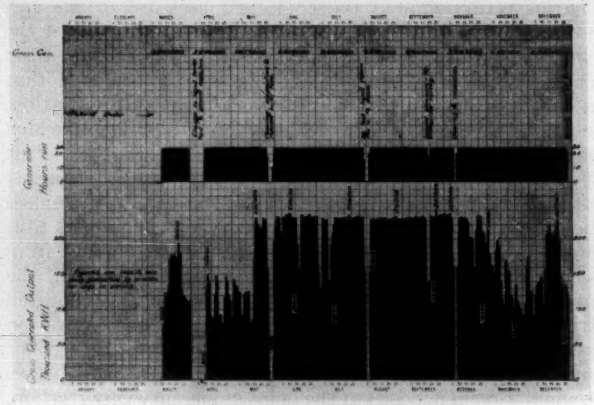


Chart of generator output and running hours for year 1932.

1933 OPERATING RECORD.

Figure 29 shows the 1933 operating record. At the end of 1932 the General Electric Company requested that a tube be

FIG. 29.

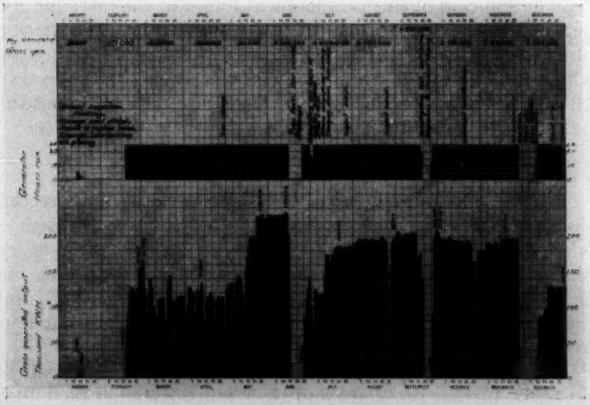


Chart of generator output and running hours for year 1933.

cut out of the drum and returned to the factory for inspection. The inspection showed the continued presence of the carbonized oil, previously mentioned, on the inside walls of the tube which would tend to cut down the heat transfer from the furnace to the mercury and it was recommended that the tubes be pickled by boiling in them a weak acid solution. In doing this the tubes acted exactly like a test tube in which water is boiled and the water hammer created by the violent ebullition caused damage to some of the strips inserted between the filler blocks in the drums; this in turn permitted the vapor stream to mix with mercury downflow and thus interfere with the circulation. The result was damage from overheating to those tubes located directly beneath the ruptured strips. Replacing these tubes and the ruptured strips took till the end of February after which the operation was normal until the end of the year except that indications appeared of occasional interference with circulation due to accumulation of deposits at the point of mercury vaporization. This was diagnosed as being iron and iron oxide picked up from erosion and held in suspension in the liquid. It was then deposited in combination with mercury oxide near the top of the tube and thus a new problem was presented—one that could not have been discovered until after long periods of operation.

The solution of this problem was found in the introduction of a small percentage of sodium into the mercury. The action of the amalgam is to dissolve the oxides and release the iron which floats into the drum. It completely cleans the iron of all oxides and silvers the tubes. This materially improves the heat transfer and thus increases the capacity of the boiler.

1934 OPERATION RECORD.

Figure 30 shows the 1934 operating period. This record shows that the only two material shutdowns were caused,—one by the discovery of the fact that certain of the iron space blocks in the drums had become loosened and were floating on the surface of the mercury instead of being submerged, and the other for the purpose of making minor changes incident to the insertion of the before-mentioned sodium.

And there the story stops for the present. There will of course be further problems and their solutions must be found,

FIG. 30.

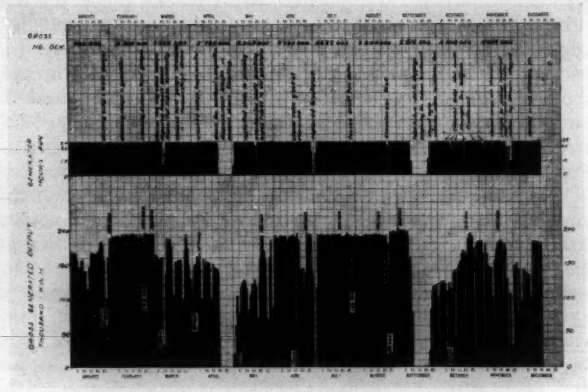


Chart of generator output and running hours for year 1934.

but now instead of one, there are three large power plants as well as the boilers used in the refineries of the Sun Oil Company from which to acquire experience. There should no longer be the long periods of lost time; this will tend to more speedily make the equipment become a regular article of commerce.

The generator output and the combined generator and condenser steam thermal efficiency is of interest.

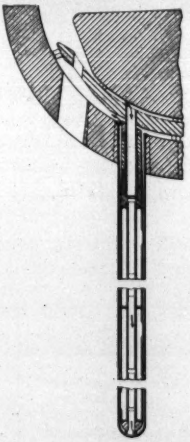
Year	Kwhrs. Mercury Only at Approx. 4,000 BTU's	Kwhrs. Total Mercury and Steam	BTU's per Kwhr.
1928	2,900,000	5,700,000	.....
1929	5,600,000	11,700,000	11,200
1930	52,500,000	121,000,000	10,300
1931	5,400,000	12,700,000	11,300
1932	49,400,000	110,000,000	10,600
1933	43,000,000	102,000,000	10,500
1934 (to Dec. 1)	48,000,000	115,300,000	10,500
	206,800,000	478,400,000	

Before discussing the question of efficiency it would be well to glance at a boiler tube as shown in section in Fig. 31.

The central tube passing through the core is the path of the mercury downflow. The liquid, after reaching the bottom, rises in the hot zone of the outer tube and is turned into vapor at some point one-half to two-thirds up from the bottom. It then passes into the drum where its path through the liquid mercury is carefully guided in order that there be no interference with the downflow. In this way each of the 3,100 tubes is a little boiler in itself, each with its own circulation system.

The complexity of this multitude of little boilers and the impossibility of internal inspection or cleaning is a practical disadvantage which the experiments now being carried on at the Old Dutch Point Station are designed to overcome. The boiler there being tested, while requiring a larger volume of

FIG. 31.



Detail of mercury boiler tube construction.

mercury, has the great advantage of the ordinary boiler construction with drums at each end of the tubes, a normal circulation and complete accessibility of tubes for inspection and cleaning—but here again, other new problems are introduced, not all of which have yet been completely solved.

Figure 32 shows the results of a twenty-four hour test most carefully conducted by the engineering firm of Stone and Webster.

I am sorry, as plotted, the zero points of the ordinates are not shown, as without them the extreme flatness of the efficiency curve at all loads can be visualized only with difficulty. It can be seen, however, that the change in heat units per kwhr. required from one-third load to full load, is only from 10,600 to 10,100 or only 5 per cent., while the fluctuations from one-half load to full load are less than 1 per cent. plus or minus.

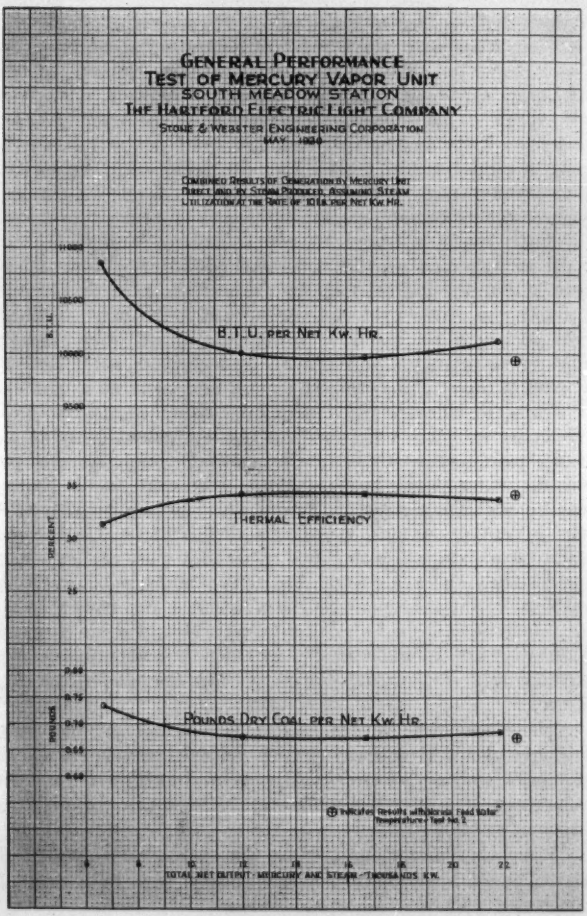
That these test results are conservative and do not represent the abnormally favorable conditions often met in test and not duplicated in regular performance, is obvious from the records of the full year's operations in 1930–32–33 and 34 where the B.T.U.'s per kwhr. ranged only between the figures of 10,300 and 10,600—including all the losses involved in the startings and stoppings and variable loads.

This efficiency was a surprise to those companies with whom we exchanged power on a fuel increment basis as we could not afford to shut the unit down in order to conserve surplus water if the increment fuel cost were to be figured any higher than 2 mills at the outside. Before the situation was accepted as fact, we received numerous visits from auditors and engineers to check up as they were not used to a fuel produced power cost of less than 2 mills in competition with their water even when the figure was recognized as an increment which included no labor. However, it worked both ways and at night in dry weather they experienced the novelty of buying surplus steam power at the same surprising figure.

There remains only to say a few words on the very brilliant chemical research which resulted in the absolute elimination of any risk of mercury poison and in the instantaneous detection of the presence of the least trace of mercury vapor in the flue gas.

The first detector consisted of slips of paper impregnated with a selenium sulphide solution. These were hung around the boiler and turbine room and at intervals exposed to

FIG. 32.


GENERAL PERFORMANCE
TEST OF MERCURY VAPOR UNIT
SOUTH MEADOW STATION
THE HARTFORD ELECTRIC LIGHT COMPANY
STONE & WEBSTER ENGINEERING CORPORATION
MAY, 1909
COMBINED RESULTS OF GENERATION BY MERCURY UNIT
DIRECT AND BY STEAM PRODUCED, ASSUMING STEAM
UTILIZATION AT THE RATE OF 10 LBS. PER NET KW. HR.
B.T.U. PER NET KW. HR.
THERMAL EFFICIENCY
POUNDS DRY COAL PER NET KW. HR.
⊕ INDICATES RESULTS WITH NORMAL FEED WATER TEMPERATURE - TEST NO. 2
TOTAL NET OUTPUT - MERCURY AND STEAM - THOUSANDS K.W.

General performance test.

samples of the flue gas. In the presence of mercury vapor they turned black. They were also used on exploring rods for the purpose of locating a leak previously indicated as existing somewhere.

Careful medical checks were made on the men at frequent intervals and in the chemical laboratories of Trinity College, Professor Krieble worked out a most accurate quantitative test for the measurement of the most minute quantities of mercury in urine analyses. This test was so sensitive as to be at first alarming in that it disclosed the presence of more or less mercury in the samples taken from each of the men on the job. However, the alarm proved to be unfounded, as a check test on samples obtained from various dentists showed the presence of still larger amounts in each case. This comparison showed our men to test a lower mercury content than perfectly healthy dentists had acquired in the course of their work with tooth filling amalgams.

The sensitized paper detector was found to fail to detect the presence of mercury oxide and even in the presence of mercury vapor was not as sensitive as desired and, therefore, under the direction of Dr. Newkirk, the General Electric Company undertook a further research resulting in a switchboard instrument to which continuous flue gas samples are piped. The sensitivity of this instrument is too great to be expressed in any reasonable number of ciphers to be found outside of a treatise on astronomy and therefore I will only describe the routine of daily calibration.

Each day with the turbine under full load, an operator opens a door of the furnace and into the roaring flames furnishing the heat required for the production of 20,000 kw., he throws one, two and three calomel pills and the operator at the switchboard duly records the fact, as indicated on the instrument, of the presence and the amount of the mercury vapor existing in the flue gas as a result of the medical treatment just then administered to the furnace.

Needless to say many and various are the psuedo-medical jokes prevalent among the operators with reference to this daily treatment.

Forecasting Degree—Days May be Possible.—(*Heating and Ventilating*, Vol. XXXII, No. 9.) A development of much value to engineers and estimators is the study by Dr. C. G. Abbot of the Smithsonion Institution. Dr. Abbot demonstrated the dominating influence of a major solar radiation cycle of approximately 23 years on a wide variety of terrestrial phenomena, and weather forecasts on this basis were remarkably successful. The results show that temperature and precipitation at numerous points scattered over the surface of the earth show many features which approximately duplicate the conditions at the same points 23 years before. For instance the water levels of the Great Lakes reflecting the fluctuating precipitation in their drainage area, show a regular 23-year cycle and a strong suggestion of an even more significant double cycle of 46 years. After long study of solar heat changes, Dr. Abbot became able to make predictions of changes which were reflected in rainfall and temperature. Altogether he made 66 forecasts over a period of three years for different parts of the United States. Twenty-seven per cent. of them he calls excellent, forty-two per cent. he describes as good, seventeen per cent. showed half of the year a fair fit with actual conditions but deviated widely the other half, and fourteen per cent. Dr. Abbot admits frankly were bad. Dr. Abbot stresses the point that the forecasts are purely experimental. Applying his theory to a simple heating problem, it would appear that the coming winter (1935–36) in Chicago should be about 2½ per cent. warmer than normal and about 7½ per cent. warmer than a normal season in New York.

R. H. O.

SCIENCE IN THE UNITED STATES COAST AND GEODETIC SURVEY.

BY

WILLIAM BOWIE, C.E., Sc.Dr.,

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The Coast and Geodetic Survey is organized in such a way that all data needed in the construction of a nautical chart are supplied by its observers in the field and its personnel in the office.

This work consists of astronomical determinations of latitude, longitude and azimuth, the measurement of base lines, observations for triangulation, tide and current surveys, topographic and hydrographic surveys of the coast-line and adjacent waters, wire-drag surveys to detect pinnacle rocks, wrecks, glacial boulders and coral reefs, and observations for the determination of magnetic elements affecting the mariner's compass. This is one of the few government bureaus that could, if it were absolutely necessary, function without assistance from any other agency in conducting its operations.

Assistance, however, is rendered by others. The Naval Observatory furnishes accurate time determinations used in the astronomical work. The Bureau of Standards standardizes apparatus such as base tapes, thermometers and leveling rods. It graduates the circles for theodolites. Survey data secured by the Corps of Engineers in their river and harbor developments are used to keep charts up-to-date. The topographic maps of the U. S. Geological Survey are of assistance in planning field operations.

Since the bureau is designed to serve, it necessarily helps other government agencies and others outside the Federal government.

The above gives in brief outline the lines of work carried on for the construction of the nautical chart, but there is other work by the bureau not involving the chart. These consist of gravity surveys, surveys for aerial navigation,

triangulation and leveling over the interior of the country. astronomical work to furnish data used in the adjustment of arcs of triangulation, observations to determine the variation of latitude, seismological work, including the determination of the epicenters of earthquakes and investigations for increasing the resistance of engineering and architectural structures to damage by earthquake, and magnetic surveys throughout the interior of the country to determine magnetic elements useful in geophysical investigations, and useful also to the practical land surveyor.

There are three scientific phases to the work of this government agency. First, the designing and improvement of instruments. Second, the making of observations and measurements, and third, the analysis and interpretation of data.

The development of instruments involves optics, magnetics and other branches of physics. It may be said that the instruments of the Coast and Geodetic Survey are nearly as up-to-date as those of any other similar agency in the world. Constant improvements are made in our instrumental equipment. If something is done in another country that would lead us to believe that one of our instruments could be improved, changes are made accordingly. Some instruments have been designed and constructed in the office of this bureau. An outstanding example is the tide-predicting machine designed and constructed by E. G. Fischer in collaboration with R. A. Harris and other members of the Tidal Division.

The first invar level rod, so far as is known, was designed and made in the bureau's shop. It is not known definitely, but it is believed that the first portable automatic recording apparatus for radio time-signals for use with a chronograph was employed by the Coast and Geodetic Survey. This apparatus was designed by E. A. Eckhardt, then a physicist at the Bureau of Standards, assisted by J. C. Karcher and Morris Keyser. Funds were transferred from the Coast and Geodetic Survey to the Bureau of Standards for carrying on development work involved. This apparatus has been somewhat modified, but in its essential parts it is similar to the original one made by Eckhardt and his assistants.

The Coast and Geodetic Survey and the Bureau of Standards joined in purchasing an apparatus for graduating circles

of theodolites. This apparatus has been modified and improved by the Bureau of Standards. Circles graduated with it have a very high degree of accuracy. The writer knows of no theodolite circles that are graduated with any higher degree of precision than those graduated by the Bureau of Standards.

A great step forward has been made in hydrographic surveying by the perfection of echo sounding apparatus by Herbert Grove Dorsey and his assistants. The fundamental principles of the echo sounding apparatus were employed by Dr. Dorsey when he was with a commercial company making the fathometer. Later Dorsey joined the Coast and Geodetic Survey and has continued with marked success his research in the use of sound waves in determining the position of the surveying ship and the depths of the water.

The observations in the field with the instruments purchased or made in the office of the Coast and Geodetic Survey present many scientific problems. In hydrographic surveying the relation between the velocity of sound and the temperature and density of the water presents a number of very interesting and important problems, the solution of which is the subject of scientific research. Triangulation now carried on at sea by means of the radio-acoustic ranging method of locating a ship and the taut-wire method both involve scientific research and observations.

Research is involved in determination of the direction and velocity of the ocean currents and in the tidal observations used for the reduction of soundings to a single datum plane and for the determination of mean sea level.

The question frequently arises as to whether the charting of the coasts and the waters contiguous thereto will be completed at some date in the near future. The answer to this question is that the charting of the coasts will never be completed so long as the actions of man and the forces of nature change the configuration of the shorelines and the bottoms of the ocean waters. There is a constant drifting of sand along the coasts; rivers and harbors must be dredged in order to provide the necessary depth for the increasing size and depth of vessels. Storms change the shoreline, and objects that formerly were aids to the navigator may have been

shifted in position or have been destroyed and other objects may appear. The charts must show the new data.

Although for many parts of the coasts the charts are changed little and seldom through many decades, there are other sections which change rapidly and frequently. These changes must be taken into consideration by the chartmaker.

In the interior of the country the Coast and Geodetic Survey is engaged upon a very comprehensive geodetic survey involving the determination of the latitude and longitude of thousands of stations, the directions and distance between contiguous stations, and the elevations above sea level for tens of thousands of bench marks. The triangulation and leveling data are used as the basis for all classes of surveys and maps. They also have many uses in engineering operations and they are of particular value in the perpetuation of the boundary lines of public and private land.

Triangulation involves the determination of latitude, longitude and azimuth by astronomical observations, the measurements of base lines for length, and the measurement of the horizontal angles of the triangles. The astronomical work is fairly well standardized and the instruments that are used are well perfected. There are, however, scientific problems connected with the astronomical work involving the study of so-called night errors, the use of the radio time signals and the variation of latitude. The mathematics connected with the determinations of apparent places of stars, and of the latitudes, longitudes and azimuths resulting from the observations, have been standard for many years.

The measurement of base lines presented difficult scientific problems prior to about 1900. For many years the base measurements were made with metal bars of various types. Although many bases were measured with satisfactory accuracy, there were serious difficulties presented by measurements in the field. During the past few decades base measurements in this country have been made with 50-meter invar tapes. Invar is not a very stable alloy, although it has the very desirable property of a low coefficient of thermal expansion. By having the tapes restandardized at frequent intervals, the errors resulting from changes in their lengths are kept within permissible limits.

The base line is a side of a triangle, and varies in length from 4 to 15 miles, or more, depending upon the character of the terrain. The probable error of the standardization of each of the base tapes by the Bureau of Standards is seldom greater than one part in a million. The base is measured with three tapes and in both directions. If for any section of the base the difference in measurements is greater than the prescribed amount, one or more additional measurements are made. The tapes are used in pairs in such a way that there is an intercomparison of the tapes of a set on each base line. If the lengths of the sections measured with one tape differ materially and constantly from the measurements with the other two tapes, then a fourth tape is substituted for the tape that stood out from the others.

The observations for the angles of the triangles in triangulation are made with the best available theodolites. The instrument that finds greatest favor with the observers of the Coast and Geodetic Survey was designed by and the first one constructed under the direction of Mr. D. L. Parkhurst, Chief of the Instrument Division of the Bureau. In the design of this theodolite, the best features of existing theodolites were used and in addition some new ideas were incorporated into it. It is rapid in operation and gives a high degree of accuracy in the results. More recently this instrument has been made by each of several manufacturers of surveying instruments in this country.

Nearly all of the measuring of the horizontal angles of the principal chain of triangles of an arc is now done at night. Years ago observations were made on poles, targets and heliotropes, but the poles and targets could not be seen for great distances, nor could they be seen over lines of even moderate length, unless the atmosphere was exceedingly clear. With the heliotrope the observing could be done only on clear days and then only in the early morning and late afternoon, when the atmosphere is usually steady. Now the observations are made at night on the light from an automobile headlight. A special bulb makes it possible to have a very narrow cone or ray of light from the lamp. The light has been observed with the unaided eye over distances as great as a hundred and fifty miles.

In general, the observations for the measurements of the angles of a main scheme triangle are repeated 32 times. The residuals of the individual measurements are usually small, unless atmospheric conditions are very unfavorable. At times the light appears to be quite unsteady. The observer learns with experience how to make the observations on such lights in a way that will give satisfactory results.

Usually there are five triangle sides radiating from a single station. With the Parkhurst and with other high-grade theodolites the observations can be completed with 32 observations over each line within an hour and a half on an average. There are cases where these observations have been completed within one hour and with none needing to be rejected because of large residuals.

One of the largest sources of error in horizontal angle measurements is lateral refraction. The stations should be selected at places such that no line of sight lies close to the side of a hill or ridge. Then again, the instruments should be elevated to such heights above the ground as to clear the layer of the atmosphere lying close to the ground and subject to disturbance. It generally has been found that lateral refraction is at a minimum, or may be entirely absent, for a line that lies close to sloping ground, when the wind is blowing towards the slope. When it is in the opposite direction, the lateral refraction may be as much as 4″ or 5″.

The average closing error of the triangles is about 1″ and a maximum of 3″ closing error is permissible. It is only occasionally that the closing error of a triangle exceeds that amount. When it does, the stations are reoccupied for additional observations.

In spite of all that can be done in the way of making accurate horizontal angle measurements, the arc of triangulation tends to swerve more or less. This swerving is sometimes ten or fifteen times the probable error of the azimuth of a triangle side as carried through the computations. This swerving is overcome by the use of so-called Laplace stations. A Laplace station is merely a triangulation station at which both the astronomical longitude and the azimuth have been observed. A comparison of the longitude determined astronomically with that determined by the triangulation gives a

measure of the deflection of the vertical in the prime vertical at the station. With a knowledge of the amount of such tilting a correction can be derived which is applied to the observed astronomical azimuth to obtain the corrected geodetic azimuth. The corrected geodetic azimuth is held fixed in the adjustment of the triangulation. In this way the swerving of the arc is overcome. These Laplace stations are established at intervals of from six to ten quadrilaterals along an arc.

Base lines are measured at varying distances along the arcs of triangulation in order to control the lengths of the triangle sides. The spacing of the base lines depends to a large extent upon the number of triangles and the strengths of the distance angles of the triangles. In general, they are spaced at intervals of one to two hundred miles.

There are now approximately 58,000 miles of arcs of first and second-order triangulation in this country. A plan is being followed which calls for the spacing of the arcs of triangulation at intervals of about 25 miles. These are all rigidly adjusted together to form a single system for the three million square miles of our area.

In 1924 a method for adjusting a large network of arcs of triangulation was devised by officials of the Coast and Geodetic Survey. By its use a new adjustment of the triangulation net of the country was started in 1924 and was completed in 1927, under the direction of O. S. Adams.

Within three years if the present rate of progress can be maintained, the triangulation net will be developed until a 25-mile spacing of arcs is attained. Much additional horizontal control surveying will be needed as the basis for topographic mapping, but with the net so well advanced as it is now the needs of the topographic engineers can be met promptly for any area in which they may wish to operate.

The Coast and Geodetic Survey is extending a network of lines of levels over the country with lines of the first-order spaced at intervals of about 100 miles and with second-order levels run in the intermediate spaces. There are at the time of this writing about 103,000 miles of first-order and 122,000 miles of second-order levels in the net. It is expected that within the next few months the network with 25-mile spacing

of the lines will be completed, except for a few small inaccessible areas in the mountains.

The level net is tied into 21 tidal stations along the Atlantic, Gulf and Pacific coasts, at which mean sea level has been determined from a number of years of observations. The leveling net is so comprehensive and so strong that we now can feel satisfied that mean sea level as determined by tidal observations does not define an equipotential or level surface. Of course, there are some errors of observation in the leveling but the results after adjustment give at least the order of magnitude of the differences in elevation for mean sea level at the 21 tidal stations. If Galveston mean sea level be taken as the zero elevation, then mean sea level at St. Augustine, Florida, has an elevation of − 0.89 feet and the mean sea level at Boston is + 0.23 feet; at San Diego the elevation is + 1.08 feet, the elevation at San Francisco is + 1.11 feet and at Seattle, + 1.57 feet.

An adjustment of the combined level net of Canada and the United States involving about 65 thousand miles of first-order leveling was completed in 1929. This adjustment furnished the most probable values of the elevations of the junction points of the net. Those junction points were held fixed and sections of the level net adjusted to them. Mean sea level was considered to have zero elevation at each one of the 21 principal tide stations of this country and at 5 tide stations on the east and west coasts of Canada. By combining the two nets stronger elevations were obtained than if the level net of the United States had been adjusted separately.

The running of lines of precise leveling has been considered a scientific problem during many decades. Atmospheric conditions affect the observations. The effect of sunlight must be considered. The question of the stability of the earth's surface is a factor in the determination and perpetuation of elevations of bench marks. Then again, there is the problem of the non-parallelism of level surfaces at different elevations. This must be taken into account in adjusting the elevations of bench marks along the line of levels. If it is not taken into account, a circuit of leveling that has been run perfectly, so far as observations and instrumental effects are concerned, may have an apparent error of closure of as

much as 3 or 4 feet. In order to close circuits of lines the so-called orthometric correction is applied to a line of levels that is run in any other than an east and west direction, where the elevation of the terrain for the line exceeds a certain minimum.

At each one of the triangulation and leveling stations a metal tablet is set in either outcropping rock, in a permanent masonry or concrete structure, or in an especially placed block of concrete. The results of the geodetic surveys consist of these station monuments with their latitudes, longitudes and elevations. Necessarily, the station monuments are designed to last for many decades.

One of the most interesting scientific problems presented to the Coast and Geodetic Survey was the measurement of the base line near Pasadena, California, and the triangulation involved in the determination of the distance between Mt. Wilson and San Antonio Peak for use by the late A. E. Michelson in the determination of the velocity of light. The base was approximately 33,638 meters in length and was measured many times. The probable error of its length from field observations alone was only one part in 11,600,000.

In the triangulation used to transfer the length of the base to the line joining the two peaks, every precaution was taken. The closing errors of the triangles averaged only 0.55″. The maximum closing error of a triangle was 1.57″. The deflection of the vertical at each one of the stations was determined in order to correct the horizontal angle measurements because of the tilting of the axis of the instrument. The probable error of the distance between the two peaks of 35,373 meters derived from the probable error of the base measurement and from the observed angles of the triangles was one part in 6,800,000. Of course, the probable errors of the base and of the distance between the two peaks should involve the probable errors of the standardization of the base tapes. It is estimated that the actual error in the distance between the two peaks is between one part in five hundred thousand and one part in a million.

The triangulation and the leveling of the country furnish the basis for the determination of earth movements near the epicenters of earthquakes. The observations made prior

to the earthquake can be repeated. The differences in the horizontal and vertical positions before and after the earthquake furnish a means of determining how much movement had occurred and how far to the side of the fault zone the earth's surface was affected. It is a very fundamental question as to whether an earthquake is caused by regionally acting forces or by those of a more local nature. Future studies of earth movements by means of geodetic measurements should throw light on this matter.

Another line of geodetic field work consists in the determination of the values of gravity. Improvements have recently been made in the apparatus formerly used. It is hoped that in the not distant future gravimeters may be designed that will make it possible to determine the value of gravity at a field station with great accuracy in a very brief period of time. The Coast and Geodetic Survey is now using the so-called Brown apparatus, which is a development of the apparatus designed by the late T. C. Mendenhall, former Superintendent of the Coast and Geodetic Survey. With the apparatus in its original form four to five stations could be established in a month. With the Brown apparatus only one day is needed for a station and if transportation and other conditions are satisfactory, from 20 to 24 stations a month can be established.

In terrestrial magnetism and seismology there are scientific problems involving the design and operation of instruments at permanent stations and at field stations. In the case of magnetic instruments progress has been chiefly along the line of study and modification of existing instruments and of improving rather than replacing earlier instruments. Such work is being done coöperatively with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

In seismology the advance has been even more marked. instruments for recording distant earthquakes, and especially for recording strong nearby earthquakes have been developed in coöperation chiefly with the Bureau of Standards. Instruments for measuring the vibrations of buildings and other structures and of the ground have been developed in connection with earthquake studies by the Coast and Geodetic Survey and are now in active use.

Although the data secured by the Coast and Geodetic Survey for its chart construction and by its geodetic surveys are used principally for making charts and maps and in many other lines of engineering, they have many scientific uses also. The hydrographic chart furnishes the configuration of the ocean bottom. This is important in physical and biological oceanography and in physiography and geology. The continental shelf is geologically speaking a part of the continent. Its configuration is given by the accurate hydrographic chart.

Coast erosion is a subject of importance to the geologists and physiographers. The charts show the positions of the coastlines and successive issues of the chart show what changes have occurred.

The tidal data provide basic observational data for various scientific questions. Obviously, they furnish the data for the further development of tidal theory and the solution of numerous complex hydrodynamic problems. They provide, also, basic elevation datums for geophysical investigations on land and sea. In addition, the results of the tide observations enter into such investigations as the body tides of the earth and its rigidity. The study of the tides furnishes practically the only precise quantitative approach to the fundamental question of changes in the relative elevations of land and sea.

Two lines of scientific research carried on by the Coast and Geodetic Survey during the past few decades involve the use of geodetic data. One is the determination of the figure of the earth, the other is isostasy. In the former, a large measure of success has been obtained. The figure of the earth derived from geodetic data by the late John F. Hayford when in charge of the geodetic work of the Survey was adopted in 1924 by the International Geodetic Association as the International Spheroid of Reference. That Association recommended its use by those countries that had not yet adopted a spheroid for their charting and mapping and for their other scientific work, and by other countries that were using a spheroid not considered to be of sufficient accuracy and wished to have a better one.

Since Hayford derived his spheroid in 1909 there have

been accumulated vastly greater amounts of geodetic data, which are now available for deriving a new spheroid. It is hoped that this work may be undertaken very shortly. It is believed that with the great expansion of the triangulation net of the United States and with the addition of many gravity stations the figure of the earth could be derived from the three million square miles of this country which would be of even greater interest to scientific men.

While it is impossible to say that a spheroid derived from data in a restricted area only approximately one-sixtieth of the total surface of the earth will represent the average sea level surface of the whole world, yet it is possible that when the isostatic principle is applied, the figure of the earth derived from a small area will really be very close to what would be derived from geodetic data covering the entire land surface of the earth.

The Coast and Geodetic Survey has coöperated very fully with F. A. Vening Meinesz of the Geodetic Commission of Holland, who devised an apparatus for the measurement of gravity at sea aboard submarines. The staff of the Survey has made isostatic reductions for a number of Vening Meinesz' sea stations.

I have covered in this outline only a few phases of the scientific work of the Coast and Geodetic Survey that happened to be most familiar to me. To treat in a similar manner all of the work that is done by this bureau would extend this paper to undue lengths.

The Coast and Geodetic Survey, like most government organizations, is not organized primarily as a research institution. Perhaps it would be well if more research in the interpretation of data acquired by government institutions could be done by those who are in closest touch with the original data, that is, by the personnel of the institutions concerned. The Survey has always, however, been interested in the meaning of the observations it makes. In the subject of oceanic tides, the late R. A. Harris of the Survey was probably in his time the leading authority, not only of this country but of the world, and his contributions to theory are of a fundamental character and for the most part are still accepted. The theory of isostasy is in substance an inter-

pretation of the observed deflections of the vertical and intensities of gravity at various points. The Survey has not confined its work to publishing the raw material, but through Hayford and his successors has discussed it and has tried to interpret it. Probably the Survey, in recent years, has done more than any other one single organization to bring about the general acceptance of the theory of isotasy. Much of course remains to be learned, especially as to matters of detail. Investigations are now being carried on, as for some time past, in connection with the figure of the earth as a whole, the form of the geoid, the variation of latitude. earth tides and related subjects. These are essentially problems in mathematics or in theoretical physics. As a natural part of the work of the Survey, investigations have been made of the theory of map projection, a subject more nearly allied to pure mathematics; this has recently developed into a group of plane coördinate systems primarily for the use of land surveyors and topographers; these systems are really special cases of map projection.

The mass of material collected by the Survey will be utilized for scientific purposes by its personnel, as far as opportunity permits. But the material is equally available to other investigators outside the Survey; it has been used by them to a limited extent in the past and it is to be hoped that more and more they will avail themselves of it in the future.

An Electrostatic Audio Generator.—E. B. KURTZ AND M. J. LARSON (*Electrical Engineering*, Vol. 54, No. 9). This paper describes a multiharmonic machine in which the current variations are produced from definite periodic changes in capacitance. Eight discs, made of ground steel 1/16 inch thick and 15 inches in diameter, are mounted on a one inch shaft which turns in 3 self-aligning ball bearing units. Any rotation up to 2400 rpm. can be obtained by a 1/3 h.p. motor and the proper pulley or gear ratio. Radial segments are made on the faces of each disc by shellacking on aluminum foil insulated from the disc by means of a layer of heavy paper. Six segments are employed for the fundamental frequency, 12 for the second harmonic etc. Each segmented disc is connected to a slip ring which is connected to switch levers on a potential panel made up of 50 resistances of 1000 ohms each. This is connected with a variable resistance to a continuous potential of 135 volts. A wave pattern plate is designed so that when the rotating segments move parallel to it, the coincident area increases and decreases sinusoidally. This causes the capacitance between the plates to change in like manner. The conductors from the wave pattern plates are connected through switches to the grid side of a 10,000 ohm amplifier input resistance. The other end of the input resistance is grounded. The amplifier is of special design and feeds an output of 2 watts into a 500 ohm impedance line with only 50 microvolts across the 10,000 ohm input resistance.

From this very brief sketch it may be visualized that each harmonic can be controlled independently in amplitude and in phase, and provisions be made for combining any 2 or more harmonics to obtain complex wave forms. The device should have wide application. Its usefulness can be furthered by adding discs. Given the analyzed results of any periodic wave form within limits of the generator that wave readily may be synthesized, and among other suggestions is that known complex tones can be sent through communication channels to study phase and other distortions.

R. H. O.

RECENT DEVELOPMENTS IN METALS SEALING INTO GLASS.

BY

HOWARD SCOTT, A.B.

I. INTRODUCTION.

The rapidly expanding uses for sealed-off gaseous conduction devices, such as small rectifiers, grid-glow tubes and Ignitrons has directed attention to the limitations of the glass-metal seals hitherto available. A vacuum tight metal-to-glass joint is required in these devices either to conduct power into a glass vessel or to insulate electrodes from metal walled vessels. Tungsten and molybdenum serve admirably the function of conducting power through a glass wall. They seal only into hard glasses having low coefficients of expansion and therefore high resistance to thermal shock. They are, however, not available except in very simple and small shapes. They are extremely difficult to fabricate or machine and are too costly to use as vessel walls.

Mercury is the usual source of a conducting vapor in many of the devices mentioned. Its presence eliminates the possibility of using copper in such forms as the sheath on Dumet and cups or tubes for Housekeeper [1] seals. Some protection against amalgamation may be afforded by electroplating mercury resistant metals onto copper, but the permanence of such protection is questionable and the expense undesirable. High chromium-iron alloys seal into soft glass, but this glass, because of its high expansivity, has inadequate resistance to thermal shock. It is clear, therefore, that a metal is needed which seals into a hard glass, is resistant to mercury attack, can be readily machined or otherwise formed and is not unduly expensive. Such a metal will eliminate present restraints on size and capacity of sealed-off vacuum devices.

The writer's investigation of the expansion properties of

[1] *Journ. A. I. E. E.*, **42**: 954 (1923).

iron-nickel-cobalt alloys [2] suggested the possibility that alloys in this system might seal into hard glass and meet the other requirements just noted. While investigating this possibility, various obstacles were met and overcome with the result that a new metal is now available for sealing into hard glass. It is free from the major objections to the hitherto avilable sealing-in metals. The various factors involved in the development and use of the new seals are discussed in this paper.

II. PROPERTIES OF GLASSES.

It may be taken as axiomatic that, in order to make a successful seal, the expansion of the metal and glass must be substantially the same over the temperature range within which the metal and glass are both elastic. A large difference in expansion between metal and glass bonded by sealing produces stresses which may cause the glass to crack when cooled to room temperature. Some degree of differential expansion, however, is tolerable or even desirable, as will be shown later, but for the moment a perfect match may be assumed to be preferable.

The relaxation characteristics of the glass determine the upper temperature limit to which matched expansion is essential. Obviously, at temperatures where the glass is substantially plastic, equal expansion is no longer necessary. Since the iron-nickel-cobalt alloys whose expansion is comparable with that of hard glasses have only a limited temperature range of low expansivity, the temperature at which a glass becomes plastic is a vital characteristic in these considerations.

The relaxation of stress in glass under a given initial strain proceeds continuously and at a rate which rapidly increases with rising temperature. For purposes of exposition it is necessary to select arbitrarily a temperature characteristic of the relaxation range of the glass. In glass technology two such temperatures, the strain point and annealing point, are used and define well the temperature range of rapid relaxation. Stresses in the glass will decay to an inappreciable value after exposure for 15 hours at the strain point or 15 minutes at the annealing point. Values of these characteristic tempera-

[2] *Trans. A. I. M. E.*, Inst. of Metals Division, p. 506, 1930.

TABLE I.

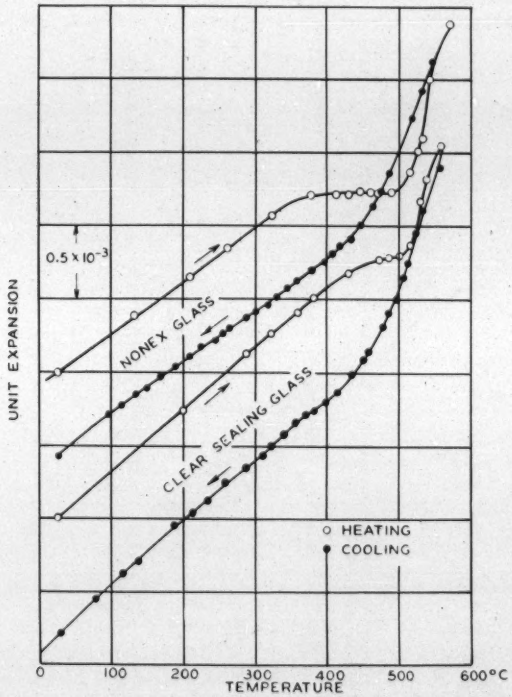
Compositions and Properties of Some Glasses Into Which Appropriate Metals are Sealed.

Glass.	Code No.	Expansivity (25 to 325° C.).	Strain Point.*	Annealing Point.†	Approximate Compositions.				
					%SiO_2.	%Na_2, K_2O.	%B_2O_3.	%PbO.	%Al_2O_3.
Soft	001	9.0×10^{-6}/° C.	389° C.	425° C.	63	14	—	21	—
Thermometer	752	6.1 " "	530° C.	566° C.	72	10	10	—	5
Clear Sealing	705	4.6 " "	461° C.	496° C.	67	6.5	22	—	2
Nonex	772	3.6 " "	486° C.	521° C.	73	4.5	16.5	6	—
(Pyrex brand chemical resistance glass)	774	3.2 " "	503° C.	550° C.	80	4	13	—	2

* Lowest temperature at which strains will decay to an inappreciable value after exposure for 15 hours.
† Same for exposure of 15 minutes.

tures are given for several important glasses in Table I. They were obtained by the method of Littleton and Roberts [3] at the Corning Glass Company and are given here through the courtesy of that concern.

FIG. 1.



Expansion curves of two hard glasses from room temperature to annealing points.

The values of expansivity given in Table I represent heating from 25 to 325° C. over which range the expansion is practically linear. In connection with sealing problems, how-

[3] *Journ. Optical Soc. Am.*, 4: 224 (1920).

ever, the expansion during cooling and over the temperature range from the annealing point to room temperature is of chief interest. Figure 1 gives expansion curves of two important hard glasses throughout that temperature range on both heating and cooling. It may be noted that the expansion from the strain point, about 470° C. for these glasses, to room temperature is much higher during cooling than on heating. Recording values of mean expansivity for the temperature ranges from room temperature to 325 and to 470° C. as in Table II, one may see that the effective expansivity on cooling

TABLE II.

Expansivity of Hard Glasses and Metals Sealing Into Them.

Material.	Direction of Temp. Change.	Expansivity.	
		25 to 325° C.	25 to 470° C.
Nonex Glass	Heating	3.5×10^{-6}/° C.	2.8×10^{-6}/° C.
" "	Cooling	3.7 " "	4.1 " "
Clear Sealing Glass	Heating	4.2 " "	3.9 " "
" " "	Cooling	4.4 " "	4.6 " "
Kovar Metal	Either	4.0 " "	5.1 " "
Tungsten Metal	"	4.7 " "	4.8 " "
Molybdenum Metal	"	5.5 " "	5.7 " "

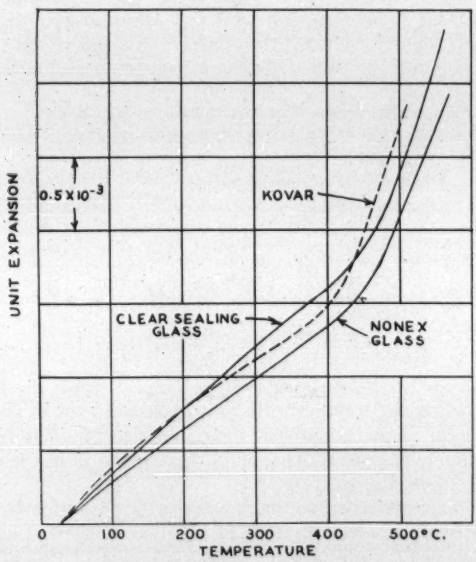
is higher for the longer temperature range. Since the lowest feasible annealing temperature of a glass is its strain point, a very useful single expansion characteristic of glass in this connection is the mean expansivity on cooling from the strain point to room temperature.

The expansion curve of a particular iron-nickel-cobalt alloy, Kovar, is given in Fig. 2, together with that of two hard glasses for comparison. The expansion of this alloy is reversible, that is, the same on heating as on cooling. Values of its expansivity over two temperature ranges together with values for tungsten and molybdenum are given in Table II. Its expansivity is lower than that of tungsten up to 450° C. and than that of molybdenum up to 500° C. These metals have the lowest expansivity of any of the pure metals. Kovar contains about 29 per cent. Ni, 17 per cent. Co, 0.2 per cent. Mn, balance iron.

It is apparent from Fig. 2 that the match in expansion

between Kovar and either glass is not perfect, but that the match is much better in the case of the "Clear Sealing" glass than in that of "Nonex." (Compositions of these glasses are given in Table I.) Though the Clear Sealing glass has a lower expansivity than Kovar at temperatures above 435° C., the discrepancy is small so that seals practically free

FIG. 2.



Expansion curve of Kovar compared with curves of two hard glasses observed during cooling from annealing point.

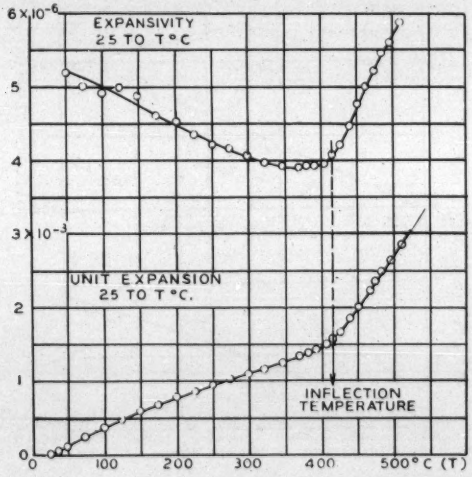
from stress can be made with this combination. In fact, serviceable seals can be made of Kovar in Nonex glass also. Other hard glasses have a still lower expansivity and higher strain point than Nonex, and, therefore, present a more difficult sealing problem. Accordingly, it is desirable to study the expansion characteristics of the iron-nickel-cobalt alloys for information on their limitations and on the manner in

which the composition of the particular alloy already considered might be advantageously modified to meet other conditions.

III. ALLOY COMPOSITION FACTORS.

For the study of composition effects, it is desirable to express the expansion characteristics of the iron-nickel-cobalt alloys simply and compactly. The various reversible compositions differ significantly only in the range of low expansivity and the effective expansivity throughout that range. The upper limit of the range of low expansivity is given by the inflection temperature, Fig. 3. For a repre-

FIG. 3.



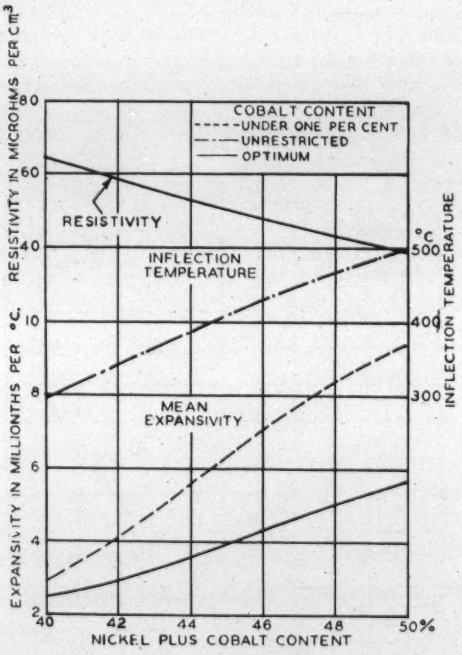
Unit expansion and expansivity of Kovar showing method of evaluating inflection temperature.

sentative value of expansivity one need take only the mean expansivity from room temperature to the inflection temperature, which range is inferred by the term mean expansivity applied to these alloys. So defined the mean expansivity and inflection temperature represent the best combination of

expansivity and temperature range of low expansivity available in a particular alloy.

The properties just called to attention are plotted against nickel plus cobalt content in Fig. 4. Peculiarly, the effects

FIG. 4.



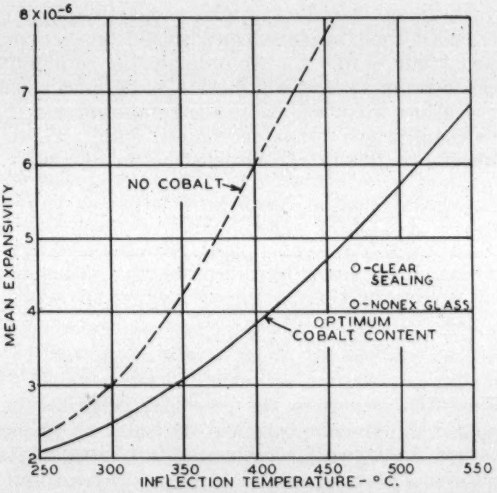
Mean expansivity, inflection temperature and resistivity of iron-nickel-cobalt alloys containing about 0.2 per cent manganese.

of nickel and cobalt on the inflection temperature are indistinguishable in the composition range considered, that is, cobalt acts as a substitute for nickel so far as this property is concerned. Consequently, it is convenient to take the nickel plus cobalt content as a composition variable, and the curve

for inflection temperatures of Fig. 4 is then not restricted to any particular relation of nickel to cobalt content.

In the absence of cobalt, that is, in plain iron-nickel alloys, low values of expansivity are also obtained, but for a given inflection temperature they are considerably higher than those obtained with optimum cobalt content, Fig. 4. The improvement on substituting cobalt for nickel is greater the higher the amount of nickel replaced up to a certain

FIG. 5.



Mean expansivity of iron-nickel-cobalt alloys containing about 0.2 per cent manganese plotted against inflection temperature. The two individual observations designated "Clear Sealing" and "Nonex" represent contraction of two glasses from their strain points to room temperature.

limit to be defined presently and the curve for mean expansivity with optimum cobalt content represents substitution to this limit. Since both the expansivity and inflection temperatures are functions of nickel plus cobalt content for a prescribed cobalt content, one may be plotted against the other as in Fig. 5 which shows clearly the best expansivity values available to a wide range of temperatures.

The limit to the benefit conferred by the substitution of cobalt for nickel is set by the Ar_3 transformation of iron. The desired low and reversible expansivity of these alloys is obtained only when this transformation is depressed below room temperature. Increasing nickel content lowers it and cobalt content raises it so the net effect of substitution is a rapid rise in the temperature at which this transformation starts. Once it occurs above room temperature the expansion curve of the alloy is no longer reversible nor is the expansivity as low as desired.

Practical considerations in alloy preparation dictate that the intended composition selected should be such that Ar_3 starts at about $-100°$ C. Accordingly, the optimum cobalt content is taken as that which, with nickel plus cobalt and other elements fixed, will cause the transformation to occur at this temperature. It is determined quite accurately for the range of compositions considered by the relation:

$$\frac{\%\ \text{Ni} + 2.5\ (\%\ \text{Mn}) + 18\ (\%\ \text{C})}{\%\ \text{Fe}} = 0.55.$$

Expressing iron content by difference, the optimum cobalt content is given by:

$$\%\ \text{Co} = 1.55\ (\%\ \text{Ni} + \text{Co}) + 3.0\ (\%\ \text{Mn}) + 18\ (\%\ \text{C}) - 55.0.$$

It may be seen from the preceding equation that the optimum cobalt content is higher the higher the manganese and carbon contents of the alloy and in fact the higher the content of any other elements that lower the Ar_3 transformation. This consideration suggests that the expansion properties can be improved still further by the addition of any such elements with a corresponding increase in cobalt content. Actually, with one known exception, the expansion properties are harmed more by the addition elements than they are benefited by the greater cobalt addition permitted.

The exceptional element is carbon. Small additions have little direct effect on the expansion properties, but permit considerably higher cobalt contents. The effects of carbon and manganese on the mean expansivity for a given inflection

temperature have already been determined quantitatively.[4] When the cobalt content is maintained at its optimum value, the mean expansivity is lowered by $0.12 \times 10^{-6/0}$ C. by an increase in carbon content of 0.1 per cent. and is raised by 0.04×10^{-6} C. by an increase in manganese content of 0.1 per cent.

Since the expansivity for a given inflection temperature is lowered when carbon is added and a corresponding substitution of cobalt for nickel is made, there is a real advantage to be gained by so doing. The amount of the carbon addition, though restricted to about 0.3 per cent., is sufficient to lower the expansivity by 0.4×10^{-6} C. Higher contents may not be retained in solid solution in which case the excess does not have the desired effect. Advantage is not taken of this expedient in the case of the Kovar compositions considered here, however, because of an undesirable effect of carbon on the glass-sealing characteristics of the alloy.

All other elements than carbon so far investigated, including manganese, do not afford even a balance between their harmful effects on the expansion properties and the benefits of the corresponding cobalt substitution. Accordingly, in the absence of carbon, these alloys should be made as pure as possible to obtain the best expansion properties. The alloy Kovar of Figs. 2 and 3 is so made, the melting stock being purified by annealing in hydrogen and melted and frozen under a hydrogen atmosphere. A manganese addition of 0.2 per cent. is made as a concession to certain metallurgical factors though not really essential. This alloy has been produced without any manganese addition in the form of a 150 pound ingot and successfully fabricated with no exceptional forging trouble.

IV. STRESSES IN SEALS.

Clear Sealing glass into which Kovar has been sealed can be obtained at room temperature practically free from stress, since the contraction of both materials on cooling from a temperature near the strain point is the same. This implies that an overnight anneal is necessary to achieve the condition

[4] Loc. cit.

of stress absence. The expansion curve of the glass, however, is parallel to that of the alloy and not far distant at temperatures between the strain and annealing point, Fig. 2. As a consequence, complete stress release can be achieved by annealing for only a few minutes with little stress development on subsequent cooling.

In the case of other hard glasses, Nonex for example, no such close match in expansivity has been attained. The mean expansivity of this glass is lower by 25 per cent. than that of the best alloy of Fig. 5. Nevertheless, successful seals between Kovar and Nonex glass can be made because the stress relations in the glass are more favorable when the metal has the higher expansivity than otherwise.

Consider for simplicity a conducting wire sealed into a glass vessel. If the major portion of the glass bead has a cylindrical form and encloses a solid round wire, the stresses produced by differential expansion can be calculated from the equations for a hollow cylinder shrunk on a solid cylinder as given by Timoshenko in his "Strength of Materials," p. 531. The equations for radial and tangential stresses in the glass are:

$$S_r = P\frac{a^2}{b^2 - a^2}\left(\frac{b^2}{r^2} - 1\right),$$

$$S_t = -P\frac{a^2}{b^2 - a^2}\left(\frac{b^2}{r^2} + 1\right),$$

where a is the radius of the metal wire, b of the overlying glass, r the radial distance from the wire axis to the point considered and P the radial stress across the boundary between metal and glass. The value of P is, of course, determined by the difference in expansion between metal and glass and their elastic constants but these need not be evaluated since only relative magnitudes are sought here. The radial stress in a seal cooled after annealing being tensional when the metal has the higher expansivity, the sign of P should be taken as positive under this condition and negative when the glass has the higher expansivity, to give the stress sign as cooled after annealing.

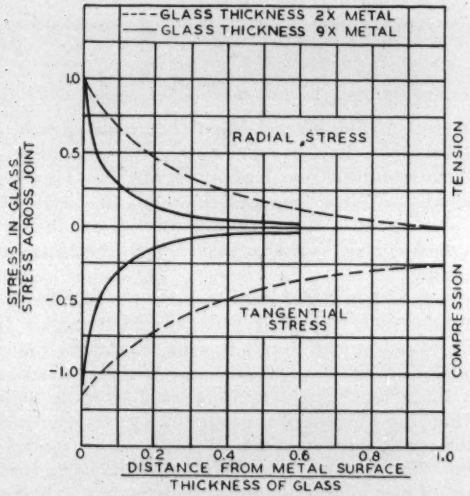
The radial and tangential stresses are a maximum at the boundary between metal and glass, Fig. 6. At this position,

the ratio of the tangential to the radial stress is:

$$\frac{b^2 + a^2}{b^2 - a^2}.$$

Thus at small diameters of the metal the values of the maximum radial and tangential stresses approach equality, but for a thin layer of glass the tangential stress may be many times the radial.

FIG. 6.



Calculated stress distribution in cylindrical sheath of glass fused to metal rod of higher expansivity than glass after annealing and cooling to room temperature.

Cracks form in glass as the direct result of tensional stresses and afford evidence of the distribution of stress prior to cracking. If now one tabulates the maximum radial and tangential stresses as in Table III, it is clear that the glass will crack in an entirely different manner when the metal has the higher expansivity than when the glass does. Assume that the metal has the higher expansivity by a sufficient degree to produce cracks though the development of thermal

TABLE III.

Maximum Tangential and Radial Stresses in a Cylindrical Glass Bead as Sealed Onto a Metal Rod, Annealed and Cooled to Room Temperature.

The value of P is determined by expansivity and elastic constants of components.

Material of Higher Expansivity.	Tangential Stress.		Radial Stress.	
	Sign.	Magnitude.	Sign.	Magnitude.
Metal.....	Compression	$\left(\frac{b^2+a^2}{b^2-a^2}\right)P$	Tension	P
Glass.....	Tension	"	Compression	"

a is radius of metal rod.
b " " " glass sleeve.

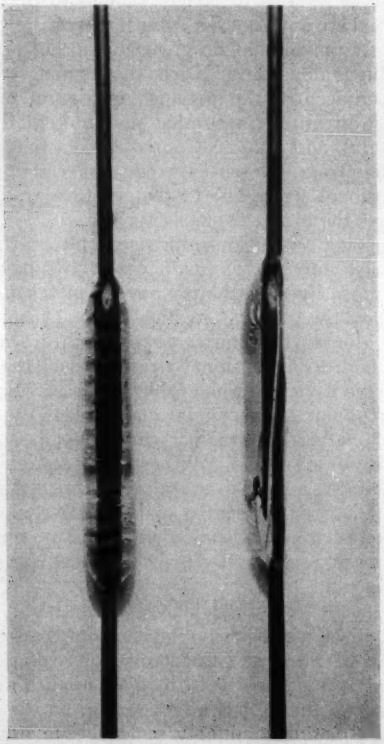
residual stresses is inhibited, then the cracks should be the direct result of radial stresses and should form close to the metal surface and more or less parallel to it. This is indeed the case, Fig. 7(*b*), for the crack that split the bead shown so started and spread. When the differential expansion is not so high, such cracks do not travel far from the metal face.

Assuming now that the glass has the higher expansivity, one would expect from the analysis of stress distribution that cracks would result from tangential or axial stresses. In fact, observed cracks are obviously due to a combination of tensional tangential and axial stress, since they take a helical path through the glass, Fig. 7(*a*). The axial stress is materially higher than the tangential for if the fracture were caused by tangential stress alone it would occur in a plane parallel to the wire axis. The axial stress could be calculated were the elastic constants of the glass and metal known, but it suffices for the present purpose to know that the axial stress is considerably higher than the tangential and of the same sign.

Since the axial stress is higher than the tangential and the tangential higher than the radial, particularly when the glass thickness is small, it is clearly preferable to have any unavoidable tensional stresses in the radial direction. This condition is achieved simply by choosing a metal of higher expansivity than the glass into which it is sealed. The need for this relation of metal to glass becomes apparent when it is stated that some residue of stress in practice is unavoidable, the

reasons being: (1) imperfect uniformity of materials, (2) lack of metals that exactly match expansivity with glasses requiring a sealed-in conductor, and (3) limitations on time available for annealing. It is undoubtedly on account of

FIG. 7.



a *b*

Cracks in beads of glass sealed on to wire 0.072 inch diameter having a mean expansivity of 8.1 × 10^{-6}/° C., beads cooled in smoky flame. (*a*) Soft glass, expansivity from 25 to 325° C. 9.2 × 10^{-6}/° C. (*b*) Hard glass, expansivity from 25 to 325° C. 4.5 × 10^{-6}/° C.

these considerations that sealing-in metals are consistently chosen with higher expansivity than the glasses into which they are sealed.

Another factor favorable to the use of a metal having higher expansivity than the glass it seals is the residual stresses induced in the glass during cooling. Seldom is it feasible to cool large seals slowly enough to prevent appreciable residual stress induction from temperature gradients in the glass. Assuming that no great fraction of the heat flow during cooling is along the wire axis, the residual stress induced in the glass adjacent to the metal is a maximum and tensional in the axial direction, presuming no differential expansion between metal and glass. Consequently, the axial compressive stress from differential expansion tends to annul the residual tensional stress due to temperature gradients when the metal has the higher expansivity.

The foregoing conclusions are based only on the case of a solid rod sealed into glass. In the case of a tube or cup seal, it is not necessarily desirable to have a metal of higher expansivity than the glass. Cracking of the glass in this case is generally due to bending stresses which are as likely to produce as high local tensional stresses when the metal has the higher expansivity as when the glass does. Nevertheless, serviceable tubular seals can be made when the metal has considerably higher expansivity than the glass, Kovar in Nonex glass, for example. With so high a differential expansion, however, a special annealing practice must be used as will be described presently and a better match in expansivity between metal and glass such as that between Kovar and Clear Sealing glass is decidedly advantageous.

V. PREPARATION OF SEALS.

A metal must meet other requirements than expansivity before it can be rated as satisfactory for sealing into glass. For one thing it must be "wet" by glass applied at a suitable temperature. Actually it is an oxide film on the metal that is wet for the metals commonly sealed become more or less oxidized during heating for sealing. Metal oxides are readily dissolved in fused glass so wetting appears to be simply the solution of glass in the oxide film on the metal. Evidently

some care must be exercised to control the oxidation for if the film is too thick it may be porous.

Iron-nickel alloys of appropriate compositions at one time were sealed directly into soft glass, but were shortly displaced by "Dumet." The copper sheath on Dumet as normally oxidized bonds with soft glass much better than the refractory oxide that forms on iron-nickel alloys at the low temperatures used in the blowing of soft glass. Substituting cobalt for part of the nickel in iron-nickel alloys to produce alloys such as Kovar improves materially the fusibility of the oxide formed. Alloys of high cobalt content are readily met by soft glass while Kovar bonds well with hard glass.

When the first seals between Kovar type alloys and hard glass were made, though no trouble was encountered in getting the glass to wet the metal, bubbles formed in the glass, adjacent to the metal surface weakening the joint. The source of the gas forming the bubbles was undoubtedly reaction between carbon in the alloy and the oxide film on its surface. In any event bubble formation was effectively eliminated by removing all carbon from the metal surface either by annealing in hydrogen or by preparing the alloy from truly carbon free components.

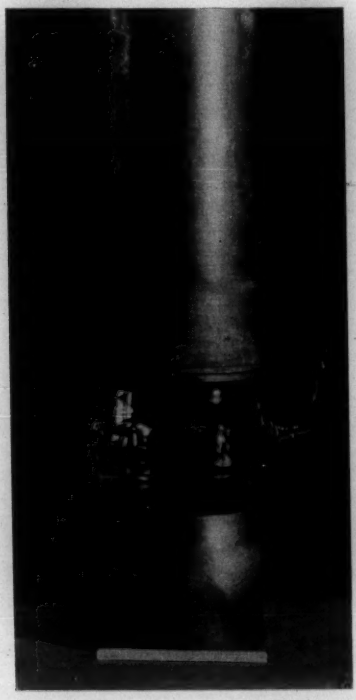
With this preparation, no special precautions are necessary to secure adhesion between Kovar and certain hard glasses. No "beading" is required unless the discrepancy in expansion is great and a long anneal is impracticable. By use of an alloy and glass whose expansitivities are relatively close, the need for a feather-edge on a tubular shape, such as is essential for sealing copper by the Housekeeper technique, is eliminated. In fact, it is preferable to have a heavy rounded edge on the metal to minimize concentration of stress in the glass. Many large seals have been made between hard glasses and tubular shapes with a wall thickness of 1/8 inch, an example of which is shown in Fig. 8.

VI. ANNEALING.

With so perfect a match in expansivity as that between Kovar and the Clear Sealing glass, the annealing procedure for least development of stress is clearly indicated. The seal while hot from the blowing operations should be cooled to the

annealing point, held there 15 minutes and then cooled to the strain point at a rate determined by the permissible residual stresses. Cooling from the strain point to room temperature can be quite rapid, the only limitation being

FIG. 8.



Seal (of Clear Sealing glass tube) between cup and tube of Kovar 4 inches in diameter.

danger of cracking from temporary stresses due to temperature gradients necessary to maintain cooling.

Our original experimental work was done, however, on the combination Kovar and Nonex glass since it presented the

most difficult of the problems which appeared susceptible of practical solution. From Fig. 2, it will be seen that the expansivity matches most closely near 400° C. while the strain point is 486° C. If the seal be annealed overnight at 486° C., no stresses will remain at that temperature, but stresses corresponding to a unit differential expansion of 0.5×10^{-3} will develop when cooled therefrom to room temperature.

An alternative method for annealing this seal is to cool to 390° C. and hold at this temperature. Complete stress release could be achieved by holding at this temperature for some days, but such a treatment is objectionable. Sufficient relaxation may occur and certainly the major part does occur during an overnight anneal. If the composition of the Kovar has been modified to give an inflection temperature of 390° C. no additional stress will develop on cooling thereafter to room temperature.

To test the foregoing possibility, wires of Kovar were sealed into Nonex glass tubes, the glass being shaped so as to give three different degrees of stress concentration. The results of annealing overnight at several temperatures are given in Table IV and show definitely that annealing below

TABLE IV.

Occurrence of Cracks in Seals of 0.115 Inch Kovar Wire Into Nonex Glass.

The seals were held overnight at the annealing temperature and cooled in air. The stress concentration factor was determined by the contour of the glass.

Annealing Temperature.	Stress Concentration.		
	Low.	Intermediate.	High.
465° C.	No cracks	Cracked	Cracked
410 "	" "	"	"
390 "	" "	No cracks	"
375 "	" "	" "	"

the strain point is effective when severe stress concentration is to be avoided. It is quite possible that relaxation of the metal also plays a part in relief of the stresses at annealing temperatures below the strain point, particularly in tubular seals. Kovar loses 50 per cent. of the maximum strain applied by bending when held 15 hours at 400° C.

Other factors contribute also to the success of the annealing procedure described. By developing maximum stress at a high temperature there is little danger of cracking for the glass then still retains some degree of plasticity. In no case have Kovar-Nonex glass seals cracked at the annealing temperature with this practice despite the high differential expansion and fast cooling to the annealing temperature. Having a high stress at the annealing temperature, rate of relaxation is more rapid than otherwise for the rate increases as the square of the stress.[5]

This treatment is effective when applied to tubular seals as well as to rods. Tubes of Kovar 2 inches diameter, 1/8 inch walls, have been sealed into Nonex glass therewith. It should be recognized, however, that a glass of higher expansivity than Nonex is preferable. The Clear Sealing glass is particularly desirable for, in addition to its more favorable expansivity, it does not devitrify under the extended heating required to make large seals. This seal has also excellent resistance to thermal shock as proved by abuse in the laboratory.

VII. SUMMARY AND CONCLUSION.

An investigation of the effects of cobalt on the expansion properties of low expansivity nickel steels revealed that a given low expansivity can be obtained to much higher temperatures by the addition of cobalt to these alloys than without. This finding introduced for the first time a possibility of sealing iron-base alloys into hard glass having an expansivity as low as 3.6×10^{-6}/°C. with a strain point up to 470° C. A particular composition having optimum cobalt content and designated Kovar is most suitable for sealing into such hard glass.

Kovar is readily wet by hard glass, that is, the natural oxide formed on it during heating fuses with the glass at glass blowing temperatures. The same is true of soft glass, particularly when the cobalt content is higher than in Kovar. Bubbles may form in the glass adjacent to the metal if the carbon content is not kept very low or other precautions taken.

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[5] Adams, J. FRANK. INST., 216: 39 (1933).

Kovar in the shape of either rod or tubes can be sealed into Nonex glass without the use of a beading glass or graded seal. Special precautions to avoid stress concentration and an unusual anneal are required, however. A more favorable glass for use with Kovar is Clear Sealing glass which contracts only slightly less than Kovar on cooling from its annealing point to room temperature. Seals of Kovar into this glass have a material advantage over one or the other of the standard seals in that they have a high resistance to thermal shock, are not attacked by mercury, and the metal is readily shaped hot or cold and is easily machined.

A study of stress relations and annealing showed that it is desirable for a metal to have somewhat higher mean expansivity than the glass into which it is to be sealed, except possibly when the joint is tubular. When the metal has a higher mean expansivity than the glass, successful seals can be made even with tubular shapes and when there is a considerable discrepancy in expansivity by avoiding high tensile stress concentration in the glass. If, in addition to the conditions just mentioned, the strain point of the glass is above the inflection temperature of Kovar, annealing overnight at a temperature below the strain point may be required as is the case with Nonex glass.

VIII. ACKNOWLEDGMENTS.

Material assistance in the development of the seals described here has been given by Messrs. Knowles and Bangratz of the Physics Division, Westinghouse Research Laboratories, who have used them in tube construction. Many of the experimental data reported were observed by Mr. J. G. Hoop of the Metallurgical Division. The writer is indebted also to Mr. P. H. Brace, Manager of the Metallurgical Division for suggestions and support during the course of this work, and to Dr. Nadai of the Mechanics Division for a mathematical analysis of stresses in seals.

Waterproofing Concrete Structures.—(*Construction Methods*, Sept. 1935.) A thin copper-bronze sheet waterproofing, claimed to cost no more than ordinary three-ply bituminous membrane, has been developed in Germany and applied to 1,000,000 sq. ft. of surface on more than 200 projects in Europe during the last 3 years. The metal insulation, laid in a hot bituminous paste and protected by a bituminous top coat, forms a weathertight waterproofing which is described as completely stable against corrosion, highly resistant mechanically, and durable for the life of any structure. By a special manufacturing process, sheets as thin as four-thousandths of an inch are rolled and supplied in strips for application on the job. The sheets have been used to waterproof culverts, tunnels, foundations and other types of structures. Tests of 0.008 in. sheets are reported to have shown that these sheets bridge a crack of 0.8 in. without drainage. The sheets can be laid by common labor in hot or cold weather without danger of blisters under the metal or defects at the joints. Joints between strips can be soldered, folded and soldered, or riveted. An example of application of this type of waterproofing, the deck of a highway bridge across the River Elbe at Weisser, Germany, was insulated with 4200 sq. yds. of copper bronze sheets 0.008 in. thick supplied in strips 44 ft. long. The installation required 15,400 lb. of copper, and the total cost of waterproofing, including bitumen and labor was almost $5000 or about 13½ cents per sq. ft.

R. H. O.

THE RELATION OF POWER TO ANTI-KNOCK FUEL REQUIREMENTS FOR MULTI-CYLINDER ENGINES.

BY

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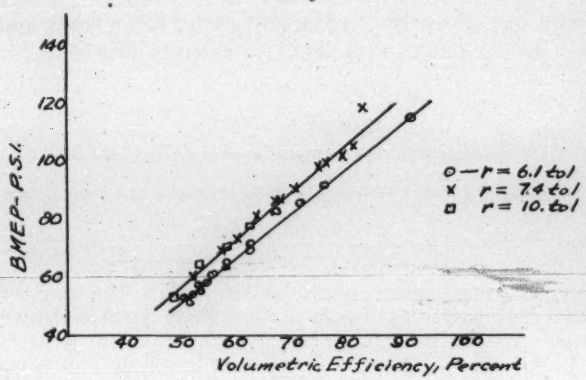
(*Concluded from November issue.*)

1B. Change in *Es* by Throttling.

We come now to an analysis of the case of a constant compression ratio engine with variable throttle. This case will be a little easier to dispose of since there are considerably more experimental data at hand applicable to our problem. The function of the throttle is to cut down the volumetric efficiency and so cut down the initial pressure, *Pi*. That is, *Pi* varies as $Ev \times Pa$. Then, by our equations already discussed, *Pc*, *Pm* and I.M.E.P. will, also, be cut down in proportion. But, *Tc* and *Tm* will be substantially unchanged depending of course upon the change in *Ti*. When an engine is throttled, we would expect an increase in the proportion of residual exhaust gases to the fresh charge. Now, although the heat added in B.T.U.'s is decreased with lower *Ev*, the weight of charge to be heated is decreased proportionately. Since this is a constant compression ratio engine, it is clear that the temperature rise during compression and combustion is practically constant as *Ev* is changed. It follows, then, that the exhaust temperature remains substantially constant also. Thus, as *Ev* is lowered and the proportion of residual exhaust gases to fresh charge increased, *Ti* will increase. We have, then, two factors with opposite influences on the knock tendency, one of which, reduced *Pc*, decreases the knock, while the other, increased *Ti*, has the opposite effect. It appears, then, that the effect of change in B.M.E.P. upon the Octane rating required will depend, again, upon the initial conditions which will determine the relative changes in *Ti* and B.M.E.P. as *Ev* is changed.

Figure 15 shows the variation in B.M.E.P. with *Ev* for a

FIG. 15.



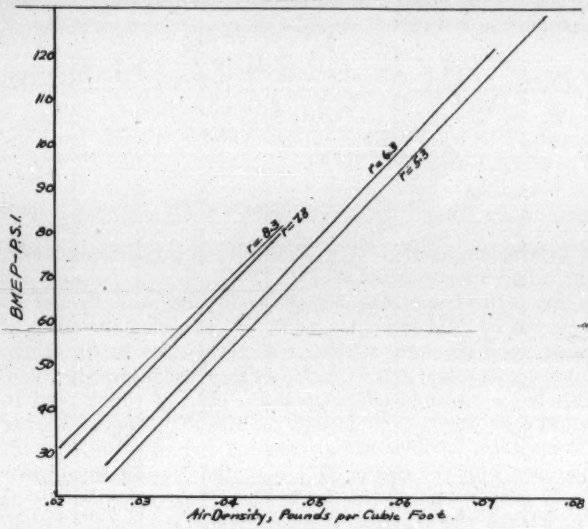
single cylinder Liberty engine running at 900 r.p.m. Figure 16 shows the variation in B.M.E.P. with air density for several compression ratios.[9] Of course, it is understood that in this section as in the one previous, I am postulating constant intake conditions of *Ta* and *Pa*, and also, constant speed and mixture strength. The condition of constant speed is added only for the sake of simplification. As a matter of fact, the effect of *Ev* upon the B.M.E.P. is independent of speed since as has long been known, the net work obtained from a unit weight of air is independent of speed.

By definition, the volumetric efficiency is the ratio of the volume of air drawn into the cylinder at carburetor inlet conditions of temperature and pressure (*Ta* and *Pa*) to the volumetric displacement of the piston during the suction stroke. Or,

$$Ev = \frac{\text{weight air entering cylinder in lbs. per stroke}}{Da \times \text{vol. displacement, cubic feet}}, \quad (12)$$

where *Da* = the density of the atmospheric air at *Ta* and *Pa* in pounds per cubic foot. If *W* equals the pounds of air per cycle, V.D. equals volumetric displacement and *Di* equals

FIG. 16.



density of the air charge inside the cylinder at start of compression stroke, we have

$$\frac{W}{\text{V.D.}} = Di \tag{13}$$

or

$$Ev = \frac{Di}{Da}. \tag{14}$$

Since V.D. is constant,

$$Ev = \frac{\text{weight of air actually drawn in}}{\text{weight of air at } Ta \text{ and } Pa}. \tag{15}$$

Thus, Ev is identical with the ratio of the weight of air actually drawn in to that which the displacement volume will hold at Ta and Pa. At one hundred per cent. volumetric efficiency, then, the charge density in the cylinder would equal the density of the external air. Now

$$W = \text{V.D.} \times Da \times Ev = \text{V.D.} \times Di, \tag{16}$$

so that

$$Pi = \frac{W \times R \times Ti}{Va} = \frac{\text{V.D.} \times Da \times Ev \times R \times Ti}{Va}, \tag{17}$$

where Va = total volume of the cylinder in cubic feet, and R = the gas constant. Then

$$Pi = \text{constant} \times Ev \times Ti. \tag{18}$$

If Ti remains constant, then, Pi is directly proportional to Ev. Since Pc varies directly with Pi, Pc is directly proportional to Ev. (In view of the proportionality between Pi and Pc they can be used interchangeably in discussing the effect of either upon detonation when r is constant.) In throttling, however, we know that Ti increases for reasons already given. This has a two-fold effect upon Pi, both of which tend to cancel each other. One is that the rise in Ti tends to lower Ev since Di is obviously decreased; the other is that Pi increases with the rise in Ti. Now the drop in Ev is practically proportional to the rise in Ti, but Pi varies directly as Ti. Hence, the net effect of a change in Ti, when throttling, is substantially as if it were constant and we may say

$$Pc = \text{constant} \times Ev.$$

We have already seen that the net work and B.M.E.P. are proportional to Ev. Since Pc is also proportional to Ev, it follows that B.M.E.P. is directly proportional to Pc, a conclusion illustrated by the data plotted in Fig. 19. These results were taken from my own work on a single cylinder Liberty engine. It follows from this brief analysis that the relation between B.M.E.P. and Octane requirement for a constant compression ratio-throttled engine will assume a form similar to that of Fig. 7, which is radically different from the functional relations obtained for the variable ratio engine as shown in Fig. 14.

We will see later that these general principles will not hold exactly for supercharged engines unless the supercharger speed is held constant, because of the effect of change in

FIG. 17.

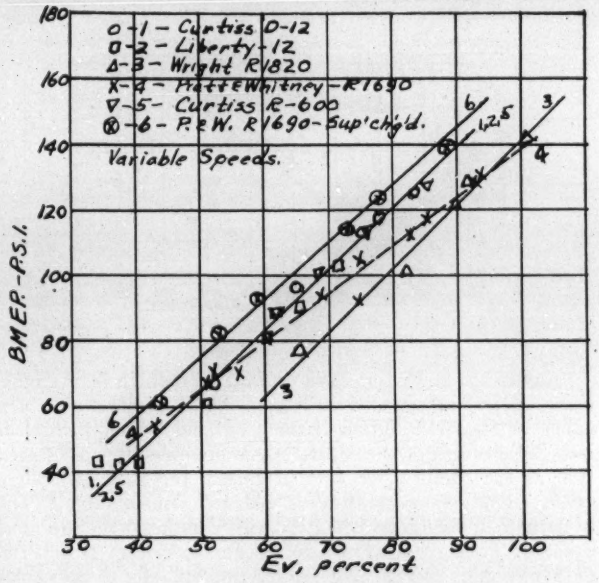
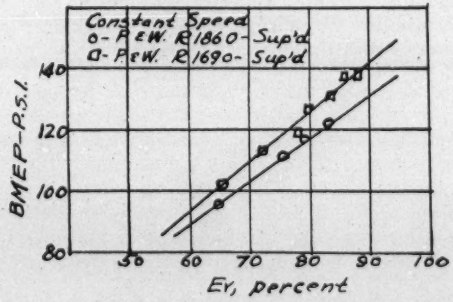
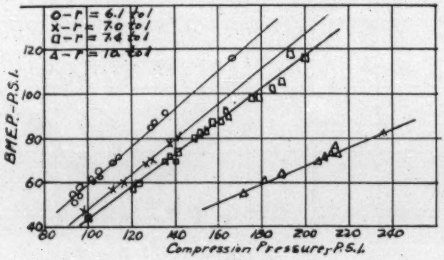

o-1-Curtiss D-12
□-2-Liberty-12
Δ-3-Wright R1820
X-4-Pratt&Whitney-R1690
▽-5-Curtiss R-600
⊗-6-P.&W. R1690-Sup'ch'g'd.
Variable Speeds.
BMEP-P.S.I.
Ev, percent

FIG. 18.


Constant Speed
o-P.&W. R1860-Sup'd
□-P.&W. R1690-Sup'd
BMEP-P.S.I.
Ev, percent

supercharger efficiencies upon the B.M.E.P. and other important variables.

FIG. 19.



1C. Change in *Ec* by Supercharging.

Figure 19 shows a most significant fact which is often lost sight of by automotive engineers when dealing with the effect of B.M.E.P. upon detonation and which brings us into the problem of the supercharged engine. It will be seen that as the compression ratio is raised, the B.M.E.P. for a given compression pressure is reduced considerably. The hypothetical change in I.M.E.P. with compression ratio for a constant *Pc* is given by the dotted curves in Fig. 11 and the data in tables 5 and 6. The curve numbers refer to the tables from which the plotted data were taken. If we neglect, for purposes of simplicity, the mixture temperature changes, when changing supercharging ratios, the relationship shown in Fig. 11 holds whether *Pc* is kept constant by change in supercharging or in throttling.

TABLE 5.

Pc = 132 P.S.I.

r.	*Pi.*	*Tc.*	*Tm.*	*Pm.*	I.M.E.P.
4	20.5	836	5470	863	299
5	14.7	925	5540	790	226
6	11.5	995	5590	742	185
7	9.13	1075	5620	690	151
8	7.56	1135	5640	656	128

Note: Table 5 calculated by the method of Table 2.

TABLE 6.

Pc = 219 P.S.I.

r.	Pi.	Tc.	Pm.	I.M.E.P.
4	36.1	530	1336	248
5	27.0	566	1265	210
6	21.6	598	1210	180
7	17.43	627	1160	153
8	14.7	652	1126	137

Note: Table 6 calculated by the method of Table 3.

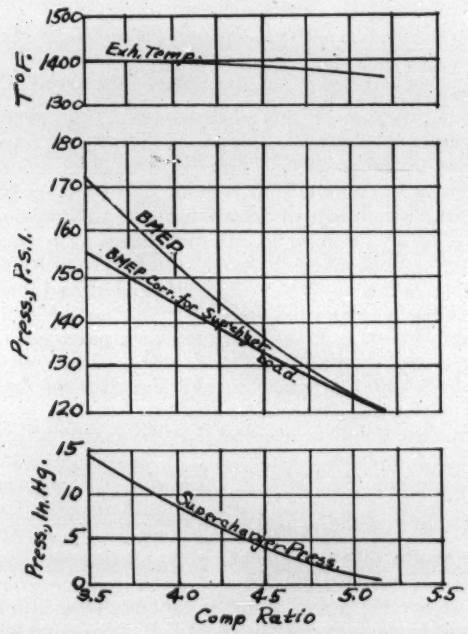
The significance of this phenomenon in the problem of fuel selection is enormous. Figure 20 gives us a glimpse into the nature of the problem. These curves, given by Taylor,[3] show that in the same engine running at a constant speed of 1510 r.p.m., simultaneous reduction of the compression ratio and increase in the amount of supercharge to a point just inside detonation, allowed higher B.M.E.P.'s to be reached with the same fuel quality. Figures 19 and 21 and the dotted curves in Fig. 11 supply at least the rudiments of an answer. Figure 21 like 19 is taken from my own work on a single cylinder Liberty fuel testing engine, already described.[2] The curves, therefore, represent empirical evidence for the hypothetical conclusions drawn from Fig. 11.

From Figs. 9 and 10, we find that Pm falls similarly with increase in compression ratio when Pc is kept constant and, as in the case of the I.M.E.P.'s, the rate of change is quite rapid. Figure 13 (dotted curves) shows that in this case the I.M.E.P. increases with Pm at an enormously greater rate and in a totally different manner when r is decreased with Pc kept constant, than when Pm was increased by increasing r alone. Hence we arrive at the paradoxical conclusion that it is possible to increase the B.M.E.P. considerably while keeping the fuel quality constant or even lowering it, or what amounts to the same thing, it is possible to so arrange our engine as to require a greater anti-knock rating while at the same time obtaining a lower B.M.E.P. This conclusion leads to a relation which is totally at odds with those arrived at in the two cases previously considered and with the curve in Fig. 6.

1D. The Effect of Inlet Air Temperature.

It is impossible, however, to dissociate the effect of inlet air charge temperature from the problem of the supercharged engine. It enters into every phase of the fuel selection problem and complicates the solution enormously. Con-

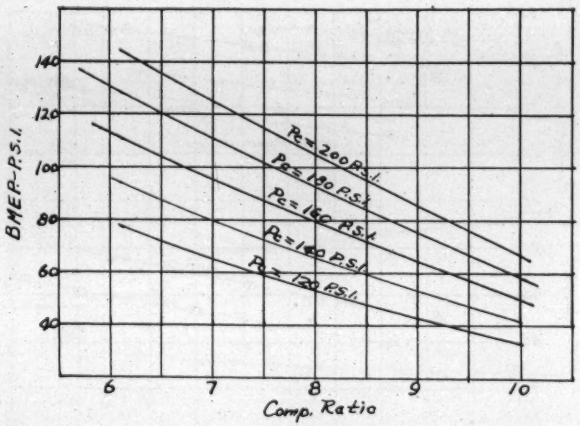
FIG. 20.



sider the curves in Fig. 22. These, taken from my own work, show the variations in a number of factors with change in the temperature of the air entering the carburetor for a constant power output. Both tests were made on highly supercharged air-cooled engines running with variable throttle opening. One had a total piston displacement of 1860 cubic inches and was run at a constant speed of 2000 r.p.m. and a

constant B.H.P. of 575. The other was of 1690 cubic inch displacement, and was operated at a constant B.M.E.P. of 144 p.s.i. at three speeds; 1860, 1910 and 1810 r.p.m. Mixture ratio and the external air conditions were approximately the same throughout the tests. It will be seen that for a given

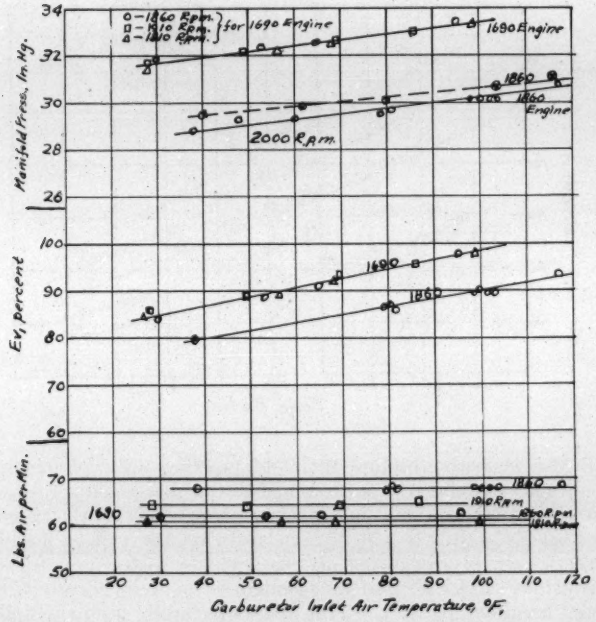
FIG. 21.



B.M.E.P. both absolute manifold pressure and volumetric efficiency are directly proportional to the charge temperature and that the relation is independent of speed within the range of speeds used. It will be seen also that for a given speed the weight of air flowing into the cylinder is constant for a constant B.M.E.P. and independent of air temperature, *Ev* and manifold pressure. This follows naturally from the well known fact that B.M.E.P. is a function of the weight of air used per cycle. I stated before, however, that this law was independent of speed. This is not true for supercharged engines for reasons I will discuss presently. The curves for the 1690 cubic inch engine showed this clearly. We have for the moment, however, a more complicated phenomenon to dispose of. I have said that for any given speed and at a

given temperature the volumetric efficiency was a function of the weight of air used per cycle. It is known also that (a) under such conditions, the B.M.E.P. is a function of the volumetric efficiency, and (b) the B.M.E.P. will fall with any increase in inlet air temperature. How, then, does it happen

FIG. 22.

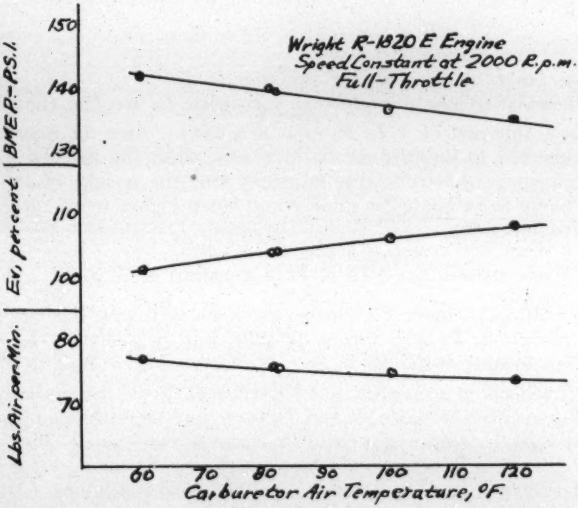


that the volumetric efficiency is increased with the inlet air temperature although both air flow mass-rate and power are kept constant or may even fall in value? Figure 23 shows how *Ev*, B.H.P. and air flow vary with change in carburetor air temperature for an engine operating at full-throttle, constant speed. It will be seen that while the mass-rate of

air flow and B.H.P. both decrease, *Ev* increases as the air temperature increases.

The reason for this fact lies in the effect of temperature upon the flow of a gas through orifices, such as the engine valve ports and carburetor throats. It has been found that

FIG. 23.



the weight of air flow through an orifice varies as $1/\sqrt{T}$ as long as the initial pressure remains constant. But the density of the air varies as $1/T$. *Ev* is proportional to the ratio of weight of flow to density. Or, *Ev* varies as $1/\sqrt{T} \times T(= \sqrt{T})$. These facts follow from the fact that while the air density varies as $1/T$, the velocity of air flow through the orifice varies as the $\sqrt{1/D}$ which varies as the $\sqrt{T}$. Since the weight of air flow is a function of density $\times$ the velocity of flow, it varies as $1/T \times \sqrt{T}(= 1/\sqrt{T})$. It follows that the B.H.P. or B.M.E.P. is also proportional to $1/\sqrt{T}$, and that they are proportional to charge density times the volumetric efficiency.

Now, how does all this affect the compression pressure? Adopting the notation of equations 12 to 18, we have for full-throttle (these considerations apply to unsupercharged as well as supercharged engines),

$$Pi = \frac{W \times R \times Ti}{Va} = \frac{\text{V.D.} \times Da \times Ev \times R \times Ti}{Va} \quad (17)$$

or

$$Pi = \text{constant} \times Da \times Ev \times Ti. \quad (19)$$

In other words, Pi is a function of $Da \times Ev \times Ti$. Remembering how these factors vary with Ta, we find that Pi is a function of $1/Ta \times \sqrt{Ta} (= 1/\sqrt{Ta})$. Now Ti may be expected to increase as Ta increases, since the exhaust gas temperature is relatively constant and the weight of fresh charge to be heated is smaller and has a higher temperature. It follows that

$$Pi = \text{constant} \times 1/\sqrt{Ta} \times Ti = \text{constant} \times W \times Ti. \quad (20)$$

In this case, then, if Ti increases as Ta increases, but not in proportion, Pi may fall as W falls, but at a slightly lesser rate, in spite of the rise in Ev. If Ti were proportional to Ta, Pi will rise in proportion to $\sqrt{Ta}$, whence, Pc will rise similarly. The relation between Pc and Ta is obvious from the fact that at a given compression ratio Pc varies directly as Pi.

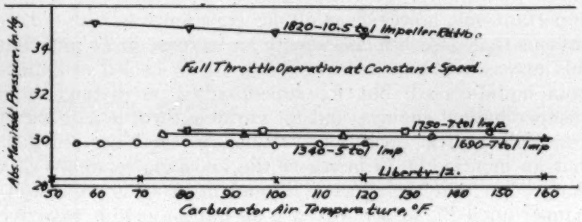
Now an increase in Ta does not change Pa whose value is determined by very complex meteorological conditions. But the density of the inlet air has been reduced according to the law

$$Da = \frac{\text{constant} \times Pa}{Ta}. \quad (21)$$

Since the weight flowing has not fallen as rapidly with increase in Ta as the density has, we conclude that the volumetric flow rate or velocity of the air has increased with Ta (as indeed it has, since Ev has increased as $\sqrt{Ta}$). The decrease in Da is in proportion, then, to $1/Ta$, whereas, the increase in flow velocity is approximately proportional to $\sqrt{Ta}$. The resistance drop across the carburetor choke and

throttle and through the intake manifolds is a function of, among other things, Da times velocity of flow. It may be expected, then, that the absolute manifold pressure will increase slightly with increasing Ta in spite of the drop in the mass-rate of air flow, a conclusion which is borne out by empirical data on unsupercharged engines.[10] The curve for the Liberty 12 engine, in Fig. 24, shows the tendency. We

FIG. 24.



have, then, an added reason, besides the one given by equation (20), for the tendency of Pc to fall, if at all, at a much lower rate than the B.M.E.P. falls when Ta is raised.

It is clear, then, that even if we disregard the effect of initial temperature upon knock tendency and consider only unsupercharged engines, shifting atmospheric conditions will greatly upset any relations we might determine to exist between B.M.E.P. and Octane rating requirement. In supercharged engines the condition is aggravated. The adiabatic efficiency of the impeller (we are discussing only the geared supercharger such as is most common with radial air-cooled engines) changes considerably with inlet conditions and with speed. It is customary in such engines to measure the manifold pressure on the pressure side of the impeller. Figure 24 contains a group of curves showing the effect of Ta upon absolute manifold pressure. It will be seen that for the relatively low 5 to 1 impeller ratio of the 1340 cubic inch engine the pressure remains constant. As the impeller speed ratio is increased, for instance to 10.5 to 1 in the 1820 cubic inch engine, the pressure shows a clear drop with increasing Ta. This would result from decreasing adiabatic efficiency

as the impeller speed ratio increased, since this efficiency is a measure of the relation of pressure rise to temperature rise through the impeller. The complications in our B.M.E.P.-fuel requirement relation arising from these factors are obvious.

1E. Effect of Mixture Charge Temperature.

The foregoing discussion has dealt mainly with full-throttle operation and has furthermore neglected the effect of initial mixture charge temperature. This factor is a very important one, however, as all our experience tells us. It is obvious that *Ti* will increase with an increase in *Ta* and that this increase will be different not only for air-cooled as distinct from liquid-cooled, but for supercharged as distinct from unsupercharged engines, and for variable throttle as distinct from full-throttle operations. When we consider, further, that an increase in *Ti* increases the knocking tendency of a charge, but that the effect is dependent in an unpredictable manner upon *Pi*, we see why it is all but impossible to arrive at any rational method of predicting the fuel requirement of an engine under variable service conditions.

To return now to our supercharged engines, consider again the curves in Fig. 22. We see that for any given B.M.E.P., the manifold pressure and volumetric efficiency increase directly as *Ta* increases regardless of speed, but, further, we find that at any given impeller speed (equivalent to constant crankshaft speed) the weight flow of air per minute is constant for the constant B.M.E.P., a result our previous experience leads us to expect. By equation (14) we have

$$W = \text{V.D.} \times Da \times Ev.$$

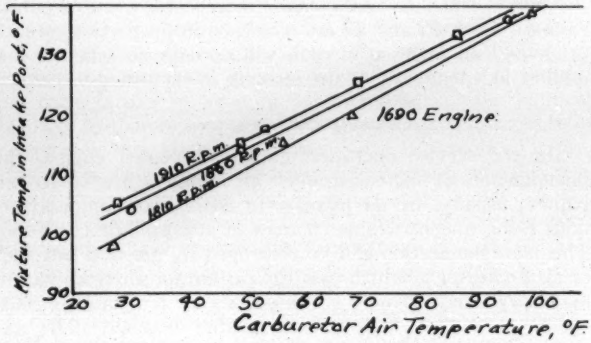
V.D. is a constant. Since the intake (atmospheric) pressure does not change appreciably with change in *Ta*, we have that

$$Da = K/Ta.$$

In order, then, that *W* remain constant, *Ev* must vary directly with *Ta*, or $Ev = k \times Ta$, where *k* is some constant. The effect of *Ta* on *Ev* and manifold pressures, however, is in the last analysis due to the effect upon *Ti*. It is extremely

difficult to measure *Ti* in the cylinder just at the start of the compression stroke, but I have determined its value in the intake valve port of the engine. These results as found for the 1690 cubic inch engine are plotted in Fig. 25. It will be

FIG. 25.



seen that this value of *Ti* is directly proportional to *Ta* for any one impeller speed. Naturally, an increase in impeller speed will increase *Ti*, an effect I will consider subsequently. The important thing here is, however, that *Ti* evidently varies with *Ta*.

We have already seen that *Da* varies as $1/Ta$. Since *W* flowing through the intake manifold is constant and the volume of these manifolds is constant, it follows that for this case *Da* must be kept constant. But

$$Da = \frac{\text{constant} \times \text{manifold pressure}}{Ta}.$$

Therefore, the manifold pressure must be increased in proportion to the increase in *Ta*. Now also, *Di* varies as $1/Ti$ and also as $1/Ta$. Again the total cylinder volume is constant (there is a negligible expansion due to the rise in cylinder wall temperature) and for a constant value of *W*, *Di* must be, also, maintained constant. Thus, if *Di* varies as Pi/Ti, *Pi* must

be directly proportional to *Ti* for a constant value of *Di* or *W*. Hence, *Pi* will vary with *Ta* according as *Ti* varies with *Ta*. We have, then, the anomalous condition, that with a rise in carburetor inlet temperature, or, mixture temperature at the intake port, constant B.M.E.P. or power is obtainable only with a considerable increase in the anti-knock fuel quality demand. This increased demand is traceable to two separate causes. Both *Pi* and *Ti* are increased in proportion to each other and an increase in each will necessitate a better fuel quality independently of the increase in the other.

1F. Cooling Air and Cylinder Head Temperatures.

In the service operation of the air-cooled engine, the phenomenon of increased inlet air temperature is accompanied, usually, by an increase in cooling air temperature, both being uncontrollable changes in atmospheric condition. This close connection can be destroyed by use of a hot spot or air preheater in which case the carburetor air temperature may vary independently of the cooling air temperature, but, again, in some wholly uncontrollable manner. The experience of various investigators has, however, been that the cooling air temperature has an effect upon power output and detonation tendency wholly independent of the effect of carburetor air temperature. The dotted curve in Fig. 22 for the 1860 cubic inch engine shows how the manifold pressure varied with *Ta* for a cooling air temperature of 105° F. The cooling air temperature for the solid curve was about 60° F. Since the B.M.E.P. was kept constant the mass flow-rate of air and therefore the volumetric efficiency was unchanged by the increase in cooling air temperature. I have found that if the throttle is kept at a constant opening, an increase in cooling air temperature results in a drop in volumetric efficiency at a given carburetor inlet temperature. In such a case, however, the manifold pressure does not change since its value is determined by inlet conditions, unless the cooling of the supercharger itself is seriously impaired.

Change in cooling air temperature operates through its effect upon cylinder head and barrel temperatures which increase in a like manner. Cylinder temperature increase results in superheating the charge in the intake valve ports

and manifolds with the result that *Ti* is increased, and *Di* decreased, in proportion. Since *Da* is (assuming *Ta* unchanged) constant, *Ev* will fall as *Di* does or in proportion to the rise in *Ti*. This accounts for the drop in power, although the manifold pressure remains constant. If, however, the lost power is to be regained, it is necessary to increase *Ev* and *Di* to the proper values, whence an increase in manifold pressure is also necessary beyond this value for the same B.M.E.P. at a lower cooling air temperature. The effect of cooling air temperature upon fuel quality demand when the carburetor air temperature is constant is, therefore, similar in most respects to that of a change in carburetor air temperature at constant cooling air temperature. Since *Di* is reduced in proportion as *Ti* increases, and manifold pressure remains constant, *Pi* (remembering that it varies as *Ev* times *Ti*) will remain substantially constant with a constant throttle opening, or, amount of supercharge, even though *Ev* and B.M.E.P. fall in value. If *Ev* is increased to its normal value so as to regain the loss in B.M.E.P., *Pi* will be increased in proportion as the manifold pressure is increased, which is to be done by an increase in throttle opening or amount of supercharging. We have, then, the same complexities introduced by cooling air temperature as by carburetor inlet temperature.

Naturally, in service the case of independent variation of either cooling or carburetor inlet air temperature, without proportionate variation of the other, is rare and somewhat hypothetical. I have discussed each separately in order to show more clearly the effects of each variable. The use of an air preheater or a mixture hot spot will approach the case of carburetor air temperature variation with a constant cooling air temperature, but cylinder temperatures, especially if they are air-cooled, will be affected just as if the cooling air temperature were varied and the problem is, thereby, made more complex than our simple analysis would indicate.

For example, although an increase in carburetor inlet or mixture temperature tends to increase the knock tendency because of the attendant rise in *Ti* and *Pi*, the actual head temperatures may fall, if the throttle opening is kept constant, because of the reduced weights of fuel and air drawn into the cylinder and the consequently lowered heat input to

the cylinder walls. On the other hand, the effect of cooling air temperature increase is to intensify the knock by an increase in the cylinder head temperature as well as in *Ti* and *Pi*. It is seen from this that cylinder head temperatures are no criteria for detonation unless considered in relation to other factors, especially intake temperatures and pressures, and then only if the cooling air and carburetor inlet temperatures are held at constant values. It is seen, also, that the effect of carburetor inlet air has two opposing phases. It has been found in testing a large number of air-cooled engines, that a rise in carburetor air temperature is accompanied by an almost linear drop in cylinder temperature for reasons which I have already discussed. In line with my purpose of dealing with a single variable at a time, I have disregarded the effect of the air temperature upon mixture strength which is, perhaps, the most disturbing factor in our whole fuel problem. It is obvious that change in air temperature will change the air-fuel ratio, first, by reason of the change in air density while the fuel flow in pounds per cycle remains substantially constant; and second, by virtue of the change in fuel viscosity at the jet. For both of these reasons an increase in the carburetor air temperature will enrich the mixture considerably, a fact which has a very important bearing on detonation tendency. For the present, however, consider that we have a carburetor control which enables us to maintain mixture strength at a constant value for maximum B.M.E.P.

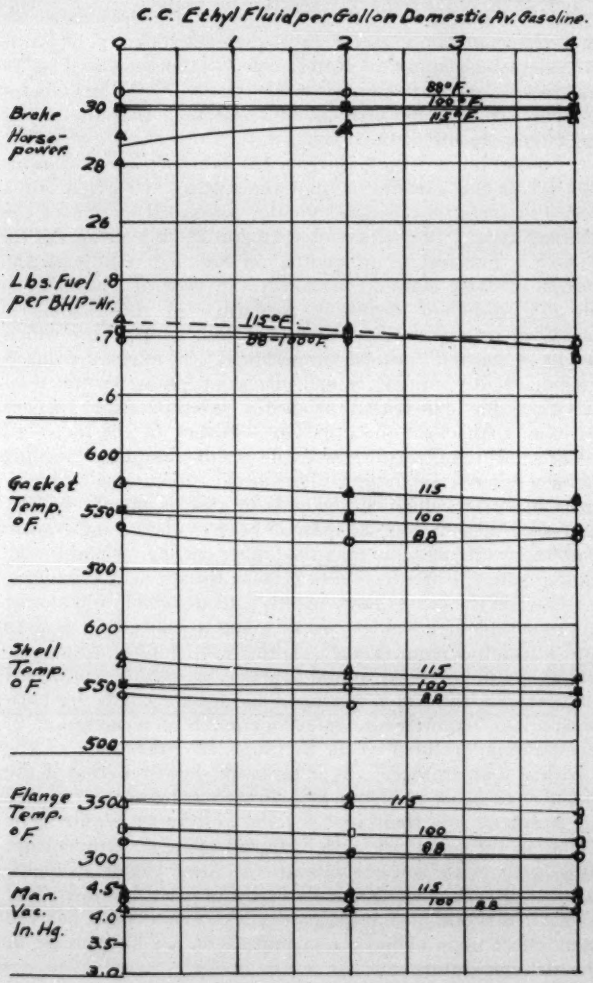
But in opposition to the phase just considered, we found that as *Ta* is increased, *Ti* is also increased, and in proportion as this latter value rose, *Pi* was either constant or increased also. But the maximum pressure of combustion varies as *Pc*/*Tc* or, since compression ratio is a constant, as *Pi*/*Ti*. If, as seems likely, *Ti* increases at a greater rate than *Pi*, which may even fall slightly, we have also a decrease in *Pm* as *Ta* increases. We have, then, the fall in *Pm* and in the cylinder wall temperature, each of which may tend to reduce the detonation tendency in opposition to the rise in *Ti* and, possibly, in *Pi*, which act in the reverse manner. The relatively greater potency of these latter two factors, which control the values of *Pc* and *Tc*, is clear from our previous

discussions and experience which showed that even with considerable drop in *Pm* and cylinder head temperatures, *Pc* was the controlling factor in inducing knock.[2] The same considerations apply to water-cooled engines as well as to air-cooled, and perhaps more emphatically, since the cylinder temperature may be kept up by controlling the flow or the inlet temperature of the cooling water.

To find more definite data on the simultaneous variations of cooling and carburetor air temperatures, I carried out a series of tests on a single cylinder air-cooled engine of the Hornet type. The range of temperature was from 60° to 115° F. The results are plotted in Fig. 26. Although the results of these tests are naturally—in view of what I have already said—not definitely indicative of the tendencies involved, it appears that below a certain temperature which might be called a "critical temperature," the effect of reduced cylinder wall temperature and maximum pressures and temperatures due to increased carburetor air temperature, appears to more than offset the opposing tendency of the increased cooling air temperature, with the result that the knocking tendency is not apparently intensified. Above this temperature, however, which in the present case is about 100° F., there is a very decided increase in both cylinder temperature and knock intensity, so that the higher cooling air and intake charge temperatures have now become the stronger influences.

How, in the face of these utterly uncontrollable and almost unpredictable happenings, are we going to relate B.M.E.P. to anti-knock fuel requirement? If the results of Fig. 26 may be taken as applicable to actual practice, it may be concluded that, even in the actual testing of an airplane engine for anti-knock fuel requirement, safety demands determination at several temperatures so as to range on either side of the "critical temperature." It is probable, however, that if the engine is to be used in temperate climates (where temperatures are normally less than 100° F.) the anti-knock requirement found on the test block with a single cooling air temperature may apply with ample safety to the same engine in flight. It must be remembered that reduction of mass flow of cooling air such as is obtained at high altitudes, or in a climb, has the same effect upon cylinder temperature as has an increase in the air temperature.

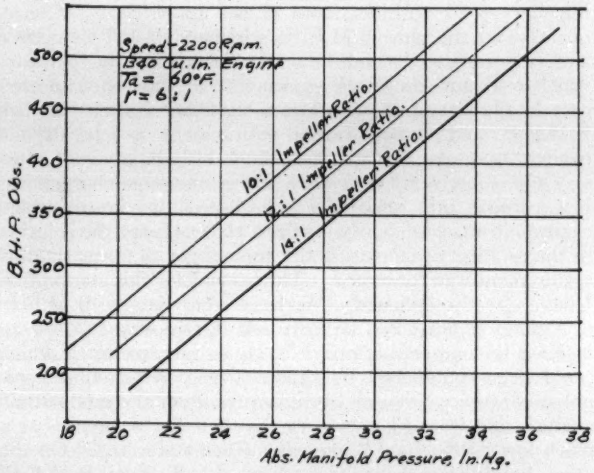
FIG. 26.


C.C. Ethyl Fluid per Gallon Domestic Av. Gasoline.
0
1
2
3
4
Brake Horse-power
30
28
26
88°F.
100°F.
115°F.
Lbs. Fuel per BHP-Hr.
.8
.7
.6
115°F.
88-100°F.
Gasket Temp. °F.
600
550
500
115
100
88
Shell Temp. °F.
600
550
500
115
100
88
Flange Temp. °F.
350
300
115
100
88
Man. Vac. In. Hg.
4.5
4.0
3.5
3.0
115
100
88

1G. The Specific Problem of Supercharging.

To return, now, to the problem of increasing volumetric efficiency by means of supercharging, consider the evidence in Fig. 27. This shows how brake horsepower at a constant

FIG. 27.



speed of 2200 r.p.m. varied with the absolute manifold pressure in an air-cooled engine with three different impeller speed ratios. The compression ratio was constant for all speeds. For a given brake horsepower, or B.M.E.P., it was necessary to run at a considerably increased manifold pressure as the amount of supercharge was increased. In conjunction with this, consult the lowest set of curves in Fig. 22. It is seen that as the speed of the impeller was increased, the mass flow-rate of air was increased for the same B.M.E.P. It is obvious, then, that *Pi* and *Pc* are increased similarly. Why? There are several possible answers. First, and, perhaps, most important, the increase in impeller speed results in an increase in the mixture charge temperature in the inlet port, i.e., *Ti* increases. The results of this rise have already been

considered. Secondly, it is probably necessary to close the throttle slightly with the result that we are encountering the thermodynamic conditions of Figs. 19 and 21 and the dotted curves in Figs. 9, 10 and 11. This, however, is not a necessary condition. Even if the throttle is held wide open, the condition of Fig. 27 still obtains. Thirdly, the higher impeller speed requires more power to drive it. Consequently, for the same B.M.E.P., a higher I.M.E.P. is needed and it is indicated conditions of pressure and temperature which determine the knock tendency. We have then another case in support of the conclusion that the relation between B.M.E.P. and Octane rating requirement is entirely dependent upon the way in which the B.M.E.P. is varied.

Only a few years ago, when the geared supercharger was just coming into successful use, especially, in air-cooled engines, it was confidently assumed that here lay the solution to the problem of increasing the horsepower so far as the fuel requirement was concerned. The reasons for this assumption I have already discussed. We have seen that the B.M.E.P. of a given engine could be increased in two ways: (a) by an increase in compression ratio; (b) by an increase in *Ev* which could be accomplished by supercharging at constant compression ratio. Now, we have seen from our thermodynamic analysis and from Figs. 9 to 12 that I.M.E.P. increases at a much lower rate than *Pc* increases when *r* is raised. On the other hand, from Figs. 15 and 19, I.M.E.P. or B.M.E.P. varies directly as *Ev* and, therefore, as *Pc*. Consequently, a given increase in B.M.E.P. will require a much greater increase in *Pc* when *r* is raised, than if the engine is supercharged. Thus, it appears that an increase in power by supercharging would require no improvement in the anti-knock quality of the fuel as compared to the requirement for a similar increase in power by raising the compression ratio. As to the empirical evidence, consult, again, Fig. 21.

But, there are serious limitations to this hopeful assertion. When it seemed a valid conclusion, impeller gear ratios were still low (not more than 6 or 7 times crankshaft speed) and the engine cylinders were small enough in size so that increased power could be matched by better cylinder cooling. Consequently, the disturbing factors of increased mixture

charge temperature and inability to hold down the cylinder head temperatures did not enter seriously into the fuel selection problem. Since then, however, cylinder sizes have increased rapidly until the problem of heat dissipation has assumed large proportions and, more important still, the impeller speeds have been greatly increased so that the heating of the mixture charge has become a veritable bogey whose effect upon fuel requirement we have already considered.

It is clear that the increase of power by supercharging has come upon serious obstacles not only in the matter of fuel but in the matter of brake-power output as well. From the evidence of Fig. 27, and the discussion about that figure, it seems obvious that the increase in brake-power obtained by raising the impeller gear ratio from 1 to 7, for instance, is far greater than would be obtained by raising that ratio from 7 to 14. Is it possible, then, that in seeking to raise the power of our engines by unlimited increase in supercharger ratios we have come to defeat our own purposes? From Figs. 22 and 25, we see that the increase in the charge temperature necessitated increasing the throttle opening in order to maintain the power constant. It is clear, then, that further increase in impeller speeds, with the consequently increased mixture temperatures in the intake port, sets up a definite limit beyond which further increase in brake-power will be impossible. A discussion of the possible remedies is beyond the scope of this present article, but it is obvious that supercharging has greatly augmented the fuel problem instead of diminishing it, and, unless some simple and adequate means of intake charge cooling is devised, power increase in the future will be a compromise between increased supercharging and increased compression. In any case, it must wait upon better fuels and better methods of cooling.

2. Effect of Air-Fuel Ratio.

At the beginning of this part of my article, I divided the determining variables into certain classifications, i.e., controllable and uncontrollable. The former included such factors as B.M.E.P., mixture strength, speed, etc. We have seen, now, that a hard and fast classification in any sense was not possible. Some of the most important sources of variation

in the controllable factor of B.M.E.P. have been the uncontrollable factors of atmospheric temperature changes. We come now to consider what is, perhaps, the most potent variable in the controllable group. There is no change to which the knock intensity of a fuel is more responsive than to that of mixture strength. But here, again, the effect upon B.M.E.P. cannot be dissociated from the other effects.

From a large number of tests, it has been fairly definitely established that a maximum B.M.E.P. is obtainable (using gasoline as the fuel) over a range of air-fuel ratios from 12.5 to 14.5 to 1, and that its variation over this wide range does not exceed one per cent. Thus, the term "mixture ratio for maximum power" is indefinite and exists only within wide limits. These limits, moreover, are not affected to any appreciable extent by changes in atmospheric temperature and barometer. A more definite point is the mixture ratio or strength for best economy at maximum power which is the leanest mixture with which maximum power or B.M.E.P. is obtainable. This point is not the same for all engines but may change from different causes, among them perfection of distribution, degree of vaporization of the fuel, friction horsepower of the engine, temperature conditions in the cylinder and valve ports, etc. It is clear, then, that not only is the mixture strength for maximum B.M.E.P. indefinite for any one engine, but the ratio for best economy at maximum B.M.E.P. is likewise indefinite unless determined for a particular engine with specific conditions.

In previous articles[1, 2] I pointed out that the great sensitivity of knock intensity to air-fuel ratio made its variation a necessary basis for evaluating the knock rating of a fuel, and was so used in my own fuel testing procedures. For a given case and conditions, the air fuel ratio for maximum knock intensity is a quite definite value in contrast to the mixture strength for maximum B.M.E.P. Moreover, the mixture strength for maximum knock intensity does not coincide with any point in the mixture range for maximum power, being somewhat on the lean side of the best economy ratio and coinciding with the mixture strength for maximum exhaust temperature. Enrichment of the mixture beyond this point results in a considerable reduction in knock in-

tensity, as does also impoverishment, but at a much lower rate. It is easy to see that the anti-knock requirement may be reduced without impairment of the power output by increasing the fuel consumption slightly. This is the principle of "fuel cooling" of an air-cooled engine. It is found that the cylinder wall temperature increases as the mixture is leaned out up to a certain point, which is somewhat leaner than the strength for maximum exhaust gas temperature. This increased heating effect, as we have already seen, tends to induce detonation even though the B.M.E.P. falls.

The effect of change in mixture strength upon detonation, therefore, is twofold, aside from its effect upon B.M.E.P. On the one hand, the knock intensity of the fuel is very sensitive to it. On the other hand, the cylinder wall temperature is similarly varied. Thus, a cumulative effect is obtained up to a certain mixture strength. This effect concerns us more in air-cooled engines than in water-cooled engines, since in the latter, the flow-rate or inlet temperature of the water may be controlled so as to keep the cylinder wall temperatures fairly constant.

Precise and sufficiently correlated practical data on the effect of mixture strength on knock requirements are lacking so that definite quantitative trends are not apparent now.

Nevertheless, much can be learned from a careful study of the results of isolated cases, and some general, if broad, conclusions can often be drawn. Take, for instance, the test of the Wright Cyclone Engine already considered. Figure 3 shows that in every case, the maximum cylinder head temperature was inversely proportional to the fuel flow. But further than this, several very significant points are revealed. The upper set shows that for three different fuels of varying anti-knock value three different slopes or rates of temperature increase are obtained. This engine did not detonate on a 1930 grade, domestic aviation gasoline doped with 2 c.c. Ethyl Fluid. It did knock rather severely on the undoped fuel. It is seen that the temperature increases at a much greater rate with the detonating fuel than with the non-knocking fuel. The unblended gasoline of 1931 grade caused a more moderate knock in the engine. It is seen that its slope lies in between those of the unblended 1930 grade and

the 2 c.c. doped fuel. From this it is concluded that it has an anti-knock value of about 1 c.c. Ethyl Fluid per gallon of 1930 grade, domestic aviation gasoline. The much lower head temperatures shown by the undoped 1930 d.a.g. is due to the much lower barometer encountered on the day this fuel was run, since it is well known that observed power and, therefore, head temperature vary directly as the barometer. The three were not run on the same day, as can be seen from the accompanying tables, but the really important thing is the increase in slope as the change from a non-detonating to a detonating fuel was made.

The second set of curves on Fig. 3 shows this up plainly. Here, the results were obtained on the same day for fuel doped with 2 c.c. and 4 c.c. Ethyl Fluid, neither of which detonated, and the undoped fuel. The change in slope is clearly seen when changing from the 2 c.c. fuel to the straight gasoline. Two very important facts are: (1) the curves for the 2 c.c. and 4 c.c. doped fuels coincide, showing that if no detonation takes place, the rate at which the head temperature increases with decrease in mixture strength does not change; and (2) the slopes of the curves are practically identical with the slopes of the curves for similar fuels shown in the top set. Further agreement with these two observations is seen from the curves in the two lower sets. Here again, the displacement of the curves is accounted for by the difference in barometer. The May 15th runs, as seen from the tabulated data for the first and third sets, were made with a much lower barometer and, therefore, developed lower head temperatures than did the others. But again, the important result is the remarkable agreement in slope of the curves between the various non-knocking and between the knocking fuels, in spite of changes in atmospheric conditions. Thus, the two-2 c.c. dope curves in the third set are parallel to each other and to the 2 and 4 c.c. curves given in the two upper figures, whereas, the two undoped 1931 gasoline curves are similarly parallel to each other and to the 1931 fuel curve in the top figure.

A third very important result of these tests is that the spark plug used has no influence on the increase in head temperature with a given fuel. Apparently, then, the spark plug has no influence upon detonation. For instance, the

two lower sets were run with the quite "hot running" 4 B type plug, with a cooler plug—the Hornet No. 3—and with the very "cool-running" BGIXB. The curves show that the slopes for all three plugs with the same fuel are identical. Figure 2 shows that the 4 B plugs operated very close to the danger point in gasket temperatures, and, hence, should have initiated knock or increased knocking severity with a detonating fuel. If the 4 B type plug had initiated knocking, as it should have done (if a "hot-running" plug is supposed to do so) the slope of its curve should have increased, and come more in line with the detonating undoped fuel curves. Again, in the case of the undoped 1931 gasoline, the curve for the 4 B plugs should have shown an increased rate of temperature rise. That no such change in slope is evident in either case would seem to indicate that the spark plug type neither influences the severity of knocking of any fuel nor affects the initiation of knock. The important conclusions to be drawn from these considerations and the curves and data of Fig. 3 may be summarized as follows:

(1) In any given engine, the rate at which cylinder head temperature increases with a decrease in mixture strength, between the limits of a best economy and a slightly over-rich mixture, is the same for all fuels which do not detonate.

(2) When detonation does occur, the rate of temperature increase is a function of the severity of the detonation, i.e., the anti-knock value of the fuel.

(3) The type of spark plug does not affect the rate of temperature rise and, therefore, apparently has no influence upon the severity of knock or its initiation.

3. Cylinder and Jacket Temperatures.

The action of change in mixture strength brings us to a reconsideration of cylinder temperatures. My earlier, brief analysis was confined to the effect of cylinder temperature through its influence upon B.M.E.P. But, we know from experience that it has an effect upon knock tendency entirely aside from its action through B.M.E.P. variations. Here again, we are faced by a dearth of controlled experimental data so that definite trends cannot be charted. In air-cooled engine cylinders, temperature is obviously a matter of cylinder

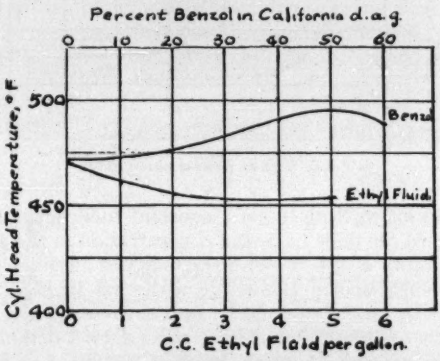
design and atmospheric condition more than operation control. In liquid-cooled engines, however, the cylinder wall temperature can be carefully controlled by varying the mass flow-rate of the cooling medium, or its inlet temperature, or the type of coolant. It is well known that an increase in the jacket temperature raises the anti-knock requirement, but from the available data as given in Table 1, it is difficult to dissociate the effect due to increased cylinder temperature from the ability to use a leaner mixture strength. Increased jacket temperatures result in higher brake thermal efficiencies, and lower radiation losses, which, in turn, result in increasing the air-fuel ratio for maximum power so that its limits include mixture strengths of greater knock intensity.

On the other hand, higher jacket temperatures increase the suction charge heating, with its consequent intensification of knock, although it is accompanied by a considerable decrease in B.M.E.P. The balance on the whole is unfavorable from the anti-knock standpoint, as can be seen by inspection of the tabulated data for the Curtiss D-12 engine. A 5.6 compression ratio engine with jacket water temperature at 180° F. operated satisfactorily with a specific fuel consumption of 0.50 pound per B.H.P. per hour, on a fuel of 48 Octane rating. When the jacket temperature was raised to 300° F., the speed being kept constant, the best economy-maximum power fuel consumption dropped to 0.44 pound per B.H.P. per hour. But, the required anti-knock rating rose to 73 Octane, while the B.M.E.P. dropped from 130 to 127 p.s.i.

It cannot be too strongly emphasized, however, that cylinder temperatures when considered by themselves are not reliable criteria for fuel requirement. We have seen that the effect must be considered in conjunction with accompanying factors and that the whole problem is immensely complicated. Considerably more light is thrown upon it by an analysis of test results reported by Parkins, Heron and others,[11, 12] which show clearly how far removed from actual multi-cylinder practice are the anti-knock data obtained in the comparatively cool running, single-cylinder, water-cooled engine. In the latter, for instance, benzol appears to be a very effective anti-knock, especially in the higher concentra-

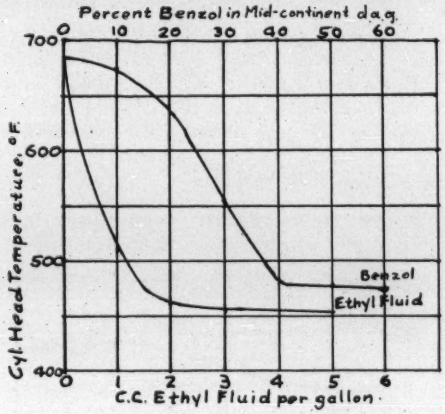
tions, since its anti-knock value increases at a much greater rate with concentration than does that of Ethyl Fluid. In fact, the latter quickly loses its efficiency beyond a definite concentration, whereas, benzol goes on being increasingly effective. But it is now known that the cylinder temperature has an enormous influence upon the Ethyl Fluid equivalent of benzol, and at the high cylinder temperatures—around 500 to 550° F.—found in large air-cooled engines benzol seems to be relatively ineffective.

FIG. 28.



Moreover, it appears from Parkins's data (Fig. 28) that, so far as their effects upon cylinder temperatures go, benzol and Ethyl Fluid act in diametrically opposed manners. It seems that Ethyl Fluid possesses some property which enables it to suppress overheating of the cylinders which cannot be accounted for by the simple suppression of knock. On the other hand, benzol tends to increase the cylinder temperature as its concentration is increased, at a rate which suggests that this overheating is independent of its anti-knock value. The overheating effect of benzol, as reported here, may be due to some reason quite aside from its combustion action as an anti-knock. Parkins does not report the operating conditions under which his data were obtained. In the absence of such description it is, perhaps, correct to assume that he

FIG. 29.



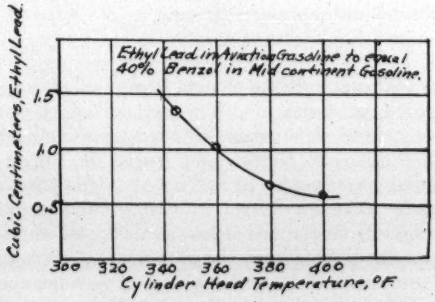
leaned out his mixture to get a constant fuel consumption as he increased the dope or benzol concentration in the gasoline. A temperature of 470° F. with the undoped gasoline, coupled with a comparison of this curve with that in Fig. 29 (also from Parkins, and, presumably, for the same type of engine) leads to the assumption that this engine did not detonate with undoped California domestic aviation gasoline, so that the addition of Ethyl Fluid or benzol would not be needed to suppress any overheating due to detonation.

Now, benzol is about 20 per cent. heavier than the base fuel. Obviously, the weight of the blended fuel will increase in proportion to the concentration of benzol. Even if the carburetor settings are left unchanged and the speed and throttle of the engine are kept constant, as they evidently were, the heavier fuel results in a leaner mixture being used as the benzol concentration is increased. On the other hand, increased molecular weight and decreased calorific power shift the mixture ratio range for maximum power and maximum exhaust temperature to the richer side as the concentration is increased. It is possible, then, that this reported overheating is the result of working at mixtures which approach

the strength for maximum exhaust temperature as the weight of the blend is increased. With the low concentrations, the increased heat effects of the shifting mixture strength would overbalance the loss in calorific power, but the two tend to become even, so that, at a concentration of around 50 per cent. benzol, the decreased heat value of the blended fuel-air mixture is so reduced as to result in reducing cylinder temperatures as the blend is increased beyond this point. Figure 29 shows clearly that when benzol is used to suppress detonation it reduces the cylinder temperature quite effectively although at not so rapid a rate as Ethyl Fluid.

The Ethyl Fluid which has practically no heat value in the very small quantities used, has, apparently, a pronounced tendency to act as a negative catalyst. It would, therefore, tend to reduce the thermal energy of combustion and the resultant radiation of heat to the cylinder walls, resulting in the reduction of cylinder temperature, aside from its effect due to the suppression of detonation.

FIG. 30.



Much more important than these considerations are the evidences that high cylinder temperatures, such as are usually obtained in air-cooled engines and high-jacket temperature liquid-cooled engines, nullify the value of benzol as an anti-knock in comparison with Ethyl Fluid. Figure 30, taken from the work of Heron and Parkins, shows how rapidly benzol loses its anti-knock effectiveness relative to Ethyl

Lead as the cylinder temperature is increased. In view of these phenomena, then, it is reasonable to conclude that for large multi-cylinder air-cooled engines Ethyl Fluid is far superior to benzol as a suppressor of detonation and, in fact, benzol is practically useless so long as the present high cylinder temperatures are encountered. Moreover, the lead-dope gasoline will allow of much cooler running than will a benzol blend of equivalent anti-knock value (as measured at ordinary single-cylinder test engine temperatures). On the other hand, these results indicate that, at equal temperatures, the lead-dope fuel will knock with greater intensity than the equivalent benzol blend. We may say, therefore, that for the present, only Ethyl Lead dope should be used to suppress normal detonation in air-cooled engines. Benzol should be resorted to only when the effective limit of Ethyl Fluid concentration (from 7 to 10 c.c. per gallon) is reached and a higher anti-knock value is desired, or when the cylinder and valve materials are subject to corrosion by Ethyl Lead. For smaller, water-cooled engines, benzol is still of considerable value, but price and availability and other items of economy make Ethyl Fluid more attractive.

4. Effect of Crankshaft Speed.

It is well known that a change in crankshaft speed affects the tendency to detonate. Whether the effect of increased speed is to reduce or increase this tendency depends upon a number of different factors and, especially, upon whether the engine is water-cooled or air-cooled. It is possible for the speed change to have a diametrically opposite effect in a water-cooled engine from the one it has in air-cooled engines. The same opposite effects may be obtained as between supercharged and unsupercharged engines. In an unsupercharged water-cooled engine, increased speed decreases the detonation tendency principally for two reasons: (a) lowered volumetric efficiency and, therefore, Pc at higher speeds, and (b) increased turbulence. These same factors operate in the unsupercharged air-cooled engine, but there is a complicating factor in the increased cylinder head temperature since the number of heat input cycles per minute is increased. This factor, resulting also in increased Ti, tends to offset the anti-

knock action of reduced *Pi* and increased turbulence, until the effects of the latter are the more potent. In such a case, increased speed will tend to increase knock tendency up to a certain point. This factor is not important in water-cooled engines because, although the water temperature rise increases with speed for the same reason, the water flow increases proportionately. It is possible, then, to keep the jacket temperature substantially constant. In the case of air-cooled engines it is true that the speed of the propeller or cooling fan increases likewise but the cooling effect is by no means increased proportionately as our practical experience shows.

If operating on fixed carburetor settings, the question is further complicated by possibilities of mixture strength variations and faulty distribution. If the maximum temperature occurs in one cylinder because of uneven distribution, speeding up will aggravate the condition and raise, considerably, the knocking tendency of the particular lean-running cylinder.

Greater complexities are added in the case of supercharged engines. To the effects already noted, must be added the knock-inducing effects of greater supercharger pressures and increased heating of the induction charge by the impeller. These latter two, especially charge heating, are often sufficient to counterbalance completely the mitigating influences of increased turbulence or reduced volumetric efficiency. From the standpoint of induction heating Ricardo found that Ethyl Lead is much superior to benzol in guarding the beneficial effects of increased speed. In any event, it is obvious that except for the simple case of the unsupercharged water-cooled engine, the effect of increased speed on the fuel requirements of a specific engine cannot be determined except on empirical grounds.

IV. CONCLUSIONS.

I have discussed, in the foregoing pages, in some detail the factors whose variations are of importance in determining the anti-knock fuel requirements in relation to the simultaneous variations in power output. I have shown how these factors, some of them controllable, some uncontrollable, are

inevitably intertwined so that complete separation of their phenomena is impossible. I have shown how, in consequence, the problem is so utterly complex that a solution of it cannot be advanced by any prediction, whether off-hand or rational, but must be the result of a series of experimental procedures for each specific engine. We have, moreover, a more serious obstacle to the formulation of a general rule for anti-knock requirements. The futility of listing such requirements in terms of Ethyl Fluid in gasoline must be evident when we see that the sensitivity of different gasolines to Ethyl Lead varies so considerably even when they have the same Octane number originally.[13] For instance, a vapor-phase and a straight run California aviation gasoline have almost the same Octane number, but the latter requires 1.6 cubic centimeters of Ethyl Lead to equal an 87 Octane ratio, while the former requires 3.6 cubic centimeters of Ethyl Lead. It is necessary, then, for a complete and reliable solution to the problem, not only to test each specific engine but to find the sensitivity of each base fuel to lead. In this jungle of apparently unrelated and contradictory variables the problem of matching fuels to performance finds itself today. It is an open question whether it can be led out of the forest by even the most complete correlation of empirical data, or anything short of the ultimate use of one base fuel and one anti-knock dope, and a single design of cylinder, valve gear and supercharger. So long as there remain the differences in these materials available for use, the complexities of the problem will remain also.

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NOTES FROM THE U. S. BUREAU OF STANDARDS.*

APPARATUS AND METHODS FOR INVESTIGATING THE CHEMICAL CONSTITUTION OF LUBRICATING OIL. THE PRELIMINARY FRACTIONATION OF THE LUBRICATING OIL FRACTION OF A MID-CONTINENT PETROLEUM.

BY

B. J. MAIR, S. T. SCHICKTANZ, and F. W. ROSE, JR.

RESEARCH NARRATIVE.

In the fall of 1933 the work of the American Petroleum Institute's Research Project 6 at the National Bureau of Standards, which up to that time had been confined to the naphtha fraction of petroleum, was extended to include the lubricating oil fraction. The object of the work is to determine what hydrocarbons are in the lubricating oil fraction. The crude oil was distilled in "vacuuo" in a semi-commercial unit. The fractions consisting of about 1 gallon each were then dewaxed by means of ethylene chloride, and the bulk of the asphaltic and resinous substances was removed by extraction with sulfur dioxide. The remainder of asphaltic and resinous substances and sulfur compounds was removed by silica gel filtration. A "water white" oil resulted from these operations. Further work has been confined to this "water white" portion which has been fractionally distilled in high vacuum.

EFFECT OF HUMIDITY IN HOT-WIRE ANEMOMETRY.

BY

G. B. SCHUBAUER.

RESEARCH NARRATIVE.

A hot-wire anemometer consists essentially of a small electrically heated wire which may be exposed to an air stream in which the speed is to be measured. Associated

* Communicated by the director.

apparatus is required for controlling the heating current and measuring the rate of heat loss from the wire.

Before the hot-wire anemometer can be used to measure air speed, it must be calibrated by measuring the heat loss, or some related quantity, in a stream of known speed, such as that in a wind tunnel. It is the universal experience of those working with hot-wire anemometers that the calibration cannot be relied upon over long periods of time. Aside from such changes as may occur due to damaging the wire in handling, other changes of a seemingly erratic nature take place which are difficult to account for and have done much to discourage the use of the instrument in precise work.

It has recently been discovered by W. Paeschke of the Kaiser Wilhelm Institut for Strömungsforschung that part of the erratic behavior is due to the effect of water vapor in the air, the heat loss from the wire increasing as the humidity increases. In an experiment recently conducted at the National Bureau of Standards the increase in heat loss was found to amount to about 2 per cent. for a relative humidity increase from 25 to 70 per cent. at 25° C. The effect is an important one in that if it is not taken into account an error of as much as 6 per cent. may be made in a determination of the air speed.

An effect of humidity is not surprising and, while only recently found by experiment, has long been suspected. If the theoretical relation between the heat loss and the air speed is considered, it is found that a change in the thermal conductivity of the air with humidity can account for the effect. The presence of a small amount of water vapor in the air is known to increase the thermal conductivity, and it is believed that the increased heat loss may be explained in this way.

DETERMINATION OF PRINCIPAL STRESSES FROM STRAINS ON FOUR INTERSECTING GAGE LINES 45° APART.

BY

WM. R. OSGOOD.

RESEARCH NARRATIVE.

When stresses in a material under load cannot be measured directly, as in a simple tensile test, for example, they may

sometimes be determined indirectly by measuring strains. In the case of plane stress, such as exists in a plate subjected to forces acting in its plane, it is possible by measuring the strains on four intersecting lines 45° apart to determine very simply the maximum and the minimum stresses in the plane of stress and also their directions. In a paper recently published by the National Bureau of Standards the equations for these stresses and their directions are given.

THE DETERMINATION OF GALLIUM IN ALUMINUM.

BY

J. A. SCHERRER.

RESEARCH NARRATIVE.

Metallic aluminum, commercially refined, always contains small amounts of certain impurities. Among these is the rare element gallium. This interesting metal, the only one other than mercury and cesium which is liquid at ordinary temperatures, has had a romantic history. Its existence was suspected by the French chemist Lecoq de Boisbaudran from a consideration of the spectral relationships of the metals of the aluminum family, and many of its properties were described quite accurately by the Russian chemist, Mendeléeff six years before Boisbaudran actually discovered it.

Gallium is widely distributed in nature and has been found in many zinc blendes, iron ores, and in nearly all bauxites. Its determination is important because it finds its way into metallurgical products, and it causes errors in the gravimetric determination of such elements as vanadium, titanium, zirconium, beryllium, etc.

The National Bureau of Standards has recently developed two procedures for the determination of gallium in metallic aluminum. In one procedure gallium is separated from aluminum in sulphuric acid solution by precipitation with the organic reagent cupferron, and finally determined indirectly in an oxide mixture containing vanadium, titanium and zirconium. In the ether procedure gallium is separated from aluminum in hydrochloric acid solution by extraction with ether. The gallium in this instance is recovered by precipita-

tion with cupferron and determined directly as gallic oxide, Ca_2O_3.

ACCELERATED SERVICE TESTS OF PINTLE BEARINGS.

BY

A. H. STANG and L. R. SWEETMAN.

RESEARCH NARRATIVE.

Few data are available as to the relative wearing qualities of the different materials which may be used for pintles or cups in lock gate pintle bearings. Since some of the lock gates in the Tennessee River development, especially at the Pickwick Lock, are of rather large size and great weight, the War Department requested the National Bureau of Standards to make accelerated service tests of pintle bearings using different combinations of materials, pressures, and conditions of lubrication.

Pintles having a diameter of 26 inches and subjected to bearing pressures of 2100 lb./in.^{2} are contemplated for use at this lock. The tangent of the angle between the axis of the pintle and the line of the resultant force on the pintle is about 0.4. The gates will swing through an angle of 70°, requiring about one minute for opening or closing. The pintle bearings will of course be under water. The estimated traffic through the lock may require the operation of the gates about 40 times a day. A life of 20 years or 288,000 cycles may be considered as satisfactory service.

The tests at the National Bureau of Standards were carried out under conditions as similar to these as practicable, with a pintle one inch in diameter. To secure results within a reasonable time, the tests were made at the rate of about 120 cycles/minute. The direction of the line of thrust and the angle of swing was the same as for the lock gate itself, and the pintle bearings were under water during the tests.

The results indicated that of the materials tested one of the materials must be phosphor bronze to give satisfactory service for pressures as great as 2,000 lb./in.^{2} Pintles of three types of monel metal gave satisfactory service at this pressure with phosphor-bronze cups.

Cup materials of stainless steel, chromium steel, chromium-nickel steel, malleable cast iron, and monel alloys were scored badly after only a few cycles when tested under a pressure of 2,000 lb./in.^{2} Aluminum-bronze cups were worn excessively at a comparatively small number of cycles. Phosphor bronze was the only cup material tested in this investigation which gave satisfactory service with pressures as great as 2,000 lb./in.^{2}

A stainless-steel pintle and phosphor-bronze cup provided with grooves for water circulation and tested under a pressure of 4,000 lb./in.^{2} withstood more than 288,000 cycles. A stainless steel pintle and phosphor bronze cup lubricated with white lead or with grease having a lead-soap base and asphalt content did not fail when tested under a pressure of 6,000 lb./in.^{2} and subjected to more than 288,000 cycles.

ACCELERATED AGING TEST FOR WEIGHTED SILK.

BY

WM. D. APPEL and DANIEL A. JESSUP.

RESEARCH NARRATIVE.

The rather rapid deterioration of some silk and particularly weighted silk fabrics in storage and as a result of exposure to light, heat, and moist air has for years been a source of trouble for manufacturers, distributors and users. The rate of deterioration cannot be predicted simply from the amount of weighting or other substances present on the silk. A laboratory test which will indicate the relative stability of silks is needed. A study of the aging of silk recently completed in the Textile Section of the National Bureau of Standards has led to a proposed accelerated aging test.

The aging, as revealed by changes in breaking strength, of a variety of silk and weighted silk cloths when stored in the dark, when exposed to the daylight received through a north window (natural aging), and when exposed to the radiation from the glass-enclosed carbon-arc lamp under controlled conditions of temperature and relative humidity of the atmosphere (accelerated aging) was studied. General agreement was found in the results of natural and accelerated

aging of fabrics which deteriorate at considerably different rates.

The accelerated aging test was applied to silk dress fabrics purchased in stores in different parts of the country. The strength after aging of the 9 fabrics containing less than 10 per cent. of nonfibrous materials varied from 87 per cent. to 42 per cent. of the original strength. The strength of the 13 weighted silks in the lot varied from 65 per cent. to 22 per cent. of the original strength.

The proposed accelerated aging test follows:

Specimens of the cloth suitable for warp and filling breaking strength tests are exposed for 20 hours to the radiation from a glass-enclosed carbon-arc lamp, such as the Fade-Ometer, operated on direct current of approximately 13 amperes with the voltage across the arc approximately 140 volts. The distance from the specimens to the center of the arc is 15 inches. The specimens are enclosed in a cabinet glazed with window glass approximately 1/8 inch thick between the specimens and the arc. The air in the cabinet is maintained at 75 to 77 per cent. relative humidity and 63 to 67° C. The breaking strength of the cloth after exposure expressed as a percentage of the breaking strength before exposure in the direction, warp or filling, showing the greater change in strength is taken to be indicative of the probable relative stability of the fabric with respect to exposure to light, heat, and moist air.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, NOVEMBER 20, 1935.

The regular monthly meeting of The Franklin Institute was called to order at 8:15 o'clock by the President, Mr. Nathan Hayward. The President announced that as this was the monthly meeting there would be certain business to be transacted and therefore called upon the Assistant Secretary for that business. He announced that the Minutes of the October meeting had been published in the November issue of the JOURNAL of the Institute, and if there were no objections or corrections they should be approved at this time. As there were no objections, the President declared the Minutes of the last meeting approved.

The Assistant Secretary reported that seventy-three members had been added to the roster since the last meeting.

The Board of Managers recommended the adoption of the following amendment to the By-Laws relative to Museum Life Members:

Amend Article II—Members, Section 9, by adding the following paragraph:

(*c*) Museum Life Memberships: Such memberships shall extend unlimited admission to the museum and planetarium to any individual who shall pay the sum of one hundred dollars ($100) in any one year. This membership shall not be transferable.

On motion duly seconded the amendment was unanimously adopted.

Announcement was made of the Christmas Week Lectures through the James Mapes Dodge Foundation. These lectures will be given on December 26th and 27th at 3 o'clock P.M. and on the morning of December 28th at 11 o'clock. Dr. E. L. Manning of the Research Laboratory of the General Electric Company will be the speaker. His subject is "The New Country of the Real Lilliputians," and will include an account of the discovery of x-rays, radioactivity, the electron, thermal electrons, and photoelectrons, high vacuum tubes, etc. He will also speak on the applications of electronic devices in industrial engineering and in human engineering. All the lectures will be illustrated by demonstrations, supplemented by lantern slides and talking moving pictures. There will also be appropriate historical exhibits.

It was also announced that there would be a special planetarium demonstration beginning on December 11th and continuing through to and including December 24th, bearing the title "The Heavens Declare." The demonstration will be accompanied by appropriate Christmas music and lighting effects.

The President called attention to the campaign for members which will begin on December 2d next and continue for about two weeks. He invited the members present to attend a meeting on next Monday afternoon, November 25th, to take a serious and important part in this campaign. A cordial invitation was also extended to those present who were not members to become members of the Institute.

The President then introduced the speaker of the evening, Dr. H. C. Rentsch-

ler, Director of Research, Westinghouse Lamp Company, who addressed the meeting on "Photoelectric Emission from Clean Surfaces."

A simple method was described for preparing a surface of any metal, regardless of its melting point or chemical activity, from which the true photoelectric properties of the metal can be determined. Slides were shown which indicated the relative sensitivities of such surfaces for equal energies of different wave lengths. Special uses of the photoelectric emission from a few of the metals were demonstrated as well as the results of treating clean surfaces with certain gases, particularly oxygen, and the changes which are thus produced. The significance of these changes upon the theories of emission from sensitized surfaces was pointed out.

After a brief discussion, a rising vote of thanks was extended to the speaker, and the meeting adjourned at 10 o'clock P.M.

ALFRED RIGLING,
Assistant Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 13, 1935.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 13, 1935.

MR. CHARLES H. MASLAND, 2D, *in the Chair.*

The following reports were presented for first reading:

No. 2975: Gyroscopic Blind Flying Instruments.

No. 3002: Planamilling and Planathreading.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

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MR. E. LEWIS BURNHAM, Retired, Philadelphia, Pa.

MR. ARTHUR R. EARNSHAW, Manufacturer, Philadelphia, Pa. For mailing: Villa Nova, Pa.

MR. GUY MARRINER, Musical Adviser to the Director, The Franklin Institute. For mailing: 301 South Seventeenth Street, Philadelphia, Pa.

MR. JOHN S. NORTH, President, North Brothers Manufacturing Company, Philadelphia, Pa.

MR. A. J. NYDICK, Patent Lawyer, Philadelphia, Pa.

MR. OSCAR L. ROBERTS, Research Chemist, Atlantic Refining Company, Philadelphia, Pa. For mailing: 846 Blythe Avenue, Drexel Hill, Pa.

MR. EDMUND STIRLING, Retired Newspaper Editor, Philadelphia, Pa. For mailing: 719 Stradone Road, Cynwyd, Pa.

NON-RESIDENT.

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NECROLOGY.

Mr. Charles C. Adsit, Des Moines, Iowa.
Mr. Frank P. Brown, Philadelphia, Pa.
Mr. Edward L. Clark, Philadelphia, Pa.
Dr. Samuel C. Hooker, Brooklyn, New York.
Mr. Robert W. Lesley, Philadelphia, Pa.
Mr. R. H. North, Philadelphia, Pa.

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BOOK REVIEWS.

A FUGUE IN CYCLES AND BELS, by John Mills. 269 pages, 13.5 × 21 cms. New York, D. Van Nostrand Company, 1935. Price $3.00.

With the impetus given to development in the physical sciences in the last quarter century, it is becoming increasingly evident that the effects are becoming felt in other fields of activity resulting in greater enjoyment and appreciation of life. A striking example of this is the effects of science on music. The Franklin Institute, primarily devoted to science, has had and has exhibited in the museum, operating scientific apparatus that facilitates the layman's understanding of noise, sound, and music, its production, reproduction and transmission. At the present time a series of lectures is given here bi-monthly with the purpose of greater music appreciation.

This book, therefore, is timely in that it attempts to bridge between science and music, presenting information which may be the basis of a revolutionary change in music itself. It is divided into four parts, beginning with a part devoted to a careful blending of the history of music and accounts of scientific developments with relation to music. Technical terms are introduced and defined in a nontechnical way, both with regard to sound and to music. It is here that the words "cycles" and "bels" are introduced.

Part II treats on telephonic studies of hearing. The results of researches of Arnold, DeForest and others in the development of the amplifier, investigations into the characteristics of speech and the sensitivity of hearing, vibrations and modulators, and tones are all discussed. This part of the book is the most difficult for the non-technical reader. Because the material is not all necessary for understanding the electrical future of music it may be skipped on the first reading and it should be by readers who are primarily interested in what electricity can do for music, the third part of the book. This starts with an interesting description and results of measurements by scientists in the Bell Laboratories on the power of musical instruments which are necessary when providing facilities for transmission and reproduction. In discussing electrical music, three practical methods are suggested which may possibly affect music to a great extent. Suppose, for instance, a composer of the future, who understands electrical possibilities, will wish at some point in a composition to enhance some chords or groups of overtones to intensities impossible to any ordinary musical instrument or to any number of players which his stage will accommodate. This may be accomplished by (1) a loud speaker-microphone arrangement with vacuum tube amplification, (2) vacuum tube oscillators may produce tones which are not of an ordinary instrument and (3) the recording phonographically on vertical cut records of the output of oscillators which can be adjusted in a laboratory until they combine to supply the needed tones.

Part IV of the book is of value to those readers who desire a brief resumé in tabular form, or graphical, of the material in the preceding text. There is also presented numerical data which supplement the discussion of the earlier chapters. Each table or chart is accompanied by a brief explanation and sometimes by a numerical illustration of its use.

This book is one that can be read by the average reader who does not wish to become overburdened by unfamiliar technical matter. Such matter can be either eliminated or skipped over rapidly. It contains a mass of factual data, at times startling revelations of results of scientific research. It should be of special value to those who desire to be informed on the state of present developments, and future possibilities of the subject.

R. H. OPPERMANN.

A SYMPOSIUM ON ILLUMINATION, edited by C. J. W. Grieveson, B.Sc. 227 pages, illustrations, plates, 14 × 22.5 cms. Pittsburgh, Instruments Publishing Co., 1935. Price $5.00.

The ten lectures of which this book is a reprint were given as a course under the auspices of the National Illumination Committee of Great Britain and the Illuminating Engineering Society in the spring of 1933 mainly at the Regent Street Polytechnic. Lieutenant-Colonel Edgcumbe who contributed the fore-

word of the book very ably sets forth that the purpose of the lectures is to give an adequate treatment of many problems of the art of illumination which is neither too technical nor too elementary. "Each chapter of this book is a transcription of one of the lectures, revised where this was necessary in order to facilitate publication. Naturally a wide range of subjects is involved, and each is dealt with by a recognized expert."

To do justice in reviewing each of the lectures is a practical impossibility in the space here allotted. The first is by Clifford C. Paterson on Lighting in the Service of Mankind which starts with a brief review of the history of lighting. From here the author goes into a discussion on the octaves of radiation, response of the eye, lighting and beauty etc.

Electric lamps and gas lamps and their characteristics are treated by a lecture on each subject. W. J. Jones with regard to electric lamps covers filament materials, efficiency, economic life, light distribution and transmission of colored bulbs. In gas lighting, F. C. Smith gives the early history, invention of the Bunsen burner and the incandescent mantle, flame temperature, aeration, distribution of light, and gas lighting units including flood lighting.

There is a lecture devoted entirely to public lighting including traffic control light signals by J. F. Colquhoun and one on lighting for safety, health and welfare by H. C. Weston. Other topics treated include radiation, photometric standards, redistribution, daylight and lighting for decoration and entertainment.

Because of the extreme clarity and thoroughness with which each topic is treated the book should find a place in the collection of everyone interested in the subject, whether from a highly specialized standpoint or from a purely general interest.

R. H. OPPERMANN.

INDUSTRIAL ELECTRONICS, by F. H. Gulliksen and E. H. Vedder. 245 pages, illustrations, 15 × 24 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1935. Price $3.50.

The wonders arising from the discovery of the electron and the invention of the vacuum and gas-filled tube seem to be countless. Almost daily, it seems, new applications are made whereby electronic devices are employed to facilitate industrial processes with the end of producing more uniform and better products at less cost. These applications considered together with the many wonderful other adaptations of the electron point to the fact that it is becoming more and more a factor in the life of every individual.

The versatility of electronic devices is not thoroughly understood by many industrialists due primarily to the rapidity of new applications. Here is where this book should have special value, for it not only describes with clarity the characteristics of tubes themselves and fundamental circuits but most of the important types of industrial applications in which electronic devices are now being used. There are nineteen chapters, the first six being devoted to descriptive and informative matter necessary to know in order to understand the fundamentals of light-sensitive tubes and cells, high vacuum and gas-filled tubes, and their circuits.

The rest of the book is based upon this foundation. There are six parts devoted to electronic instruments and control including a great many applications

of light sensitive control devices etc.; electronic regulators covering principles of automatic regulator design and voltage regulators; speed regulators; photo-electric register regulators; process regulation; temperature regulators. One equipment representative of each type of application is described in detail.

Readers of this book cannot help but be impressed with the great varieties and possibilities of the applications of industrial electronics. To industrial engineers it should point out possibilities at least, if it does not show direct applications not hitherto realized. A very interesting and useful course on industrial electronics can be presented using this book as the main text or to supplement a more fundamental course of study on electronic tubes.

R. H. OPPERMANN.

ÉLECTRO-ACOUSTIQUE, par Ph. Le Corbeiller, 87 pages, illustrations, 16.5 × 25 cms. Paris, Etienne Chiron, n.d.

In writing this somewhat condensed thesis the author hails a new technology, that of electro-acoustics. Certainly, great strides have been made in this field during the last decade or so. Witness the development of the telephone, under-water signalling, radio broadcasting, the phonograph, the talkies and the still relatively underdeveloped electrical musical instruments. It is pointed out that a systematic utilization of calculus and observational data has been chiefly responsible for these advances. Accordingly, due recognition is given to the mathematical development of the subject.

The first chapter, generally introductory in nature, deals with oscillations and wave harmonics. The matter of electro-mechanical transformers involves such concrete examples as the electrical pickup of phonographs, the telephone transmitter, the microphone and the dynamic loudspeaker. Associated closely with the foregoing is the study of mechanical-acoustic transformers which more specifically refer to the production of sound by mechanical vibrations and inversely. Under this caption will be found a discussion of variously-shaped horns or speakers. The well-known exponential type is analyzed. The generation of acoustical oscillations and the physiology of sound comprise chapters IV and V. A final chapter on measurements describes two methods for determining mechanical impedance, directions for measuring the frequency and pressures of sound waves, and also includes a section on the acoustics of rooms.

T. K. CLEVELAND.

THE METALLOGRAPHY AND HEAT TREATMENT OF IRON AND STEEL, by Albert Sauveur, S.D., Dr. Eng., fourth edition, 531 pages, illustrations, tables, 18.5 × 27.5 cms. New York, McGraw-Hill Book Company, Inc., Cambridge, The University Press, 1935. Price $8.00.

The fourth edition of this outstanding treatise by a well known author. That the book has reached its fourth edition is indicative of two things. First is that it is accepted as a well balanced, specific, and comprehensive treatise, supplying a definite need successfully, and the second is that the progress of the science has reached a point necessitating the need of a new edition to bring the subject matter up to date.

There are twenty-eight chapters to the book devoted to as many different subjects under this heading. Metallic crystals, pure and impure metals, iron and steel, thermal critical points of iron and steel, heat treatment, hardening and

tempering of steel, alloy steels and cast iron, constitution of metallic alloys, and the phase rule are all given thorough treatment in a most clarified manner. There are two appendices on the preparation of samples of iron and steel for examination.

Those who are familiar with previous editions of the book, will find two new chapters: Chapter I entitled Metallic Crystals and their Atomic Structures, and Chapter XVIII entitled A Simplified View of the Hardening of Steel, of the Transition Constituents and of the Microstructure of Steel. The former covers the underlying principles upon which the x-ray diffraction analysis of metals rests, and the latter presents the author's views of the constitution of iron-carbon alloys. In addition it will be found that nearly every chapter of the present edition has been revised to some extent.

Because of the bearing it has on the contents of the book and on modern scientific study in general, the following paragraph of the preface by the author is transcribed.

> "The reader may note that the views he (the author) now offers for his consideration, are not in full agreement with opinions previously expressed by him. The author readily admits it and does not think that he should attempt to justify it. He believes that any one engaged in scientific research or study should be prepared to discard without hesitation any view he may have held whenever a theory more plausible, simpler or better supported by experimental evidence is offered to him, or conceived by him."

The book is profusely illustrated with photographs, drawings and curves to assist in clarity of presentation. Too much cannot be said on clarity and method of presentation. The author's style is unique and should have great appeal to the student as well as to the highly trained technician.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 537, Tests in the Variable-Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward, by Eastman N. Jacobs and Robert M. Pinkerton. 9 pages, illustrations, 22.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price five cents.

A family of related airfoils having the position of maximum camber unusually far forward was investigated in the variable-density tunnel as an extension of the study recently completed of a large number of related airfoils. The new airfoils gave improved characteristics over those previously investigated, especially in regard to the pitching moment. Some of the new sections are markedly superior to well-known and commonly used sections and should replace them in applications requiring a slightly cambered section of moderate thickness, having a small pitching-moment coefficient.

Report No. 529, A Flight Investigation of the Spinning of the F4B–2 Biplane with Various Loads and Tail Surfaces, by N. F. Scudder and Oscar Seidman. 22 pages, tables, illustrations, 22.5×29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

A flight investigation of the spinning of the F4B–2 single-seat fighter airplane was made for the purpose of finding modifications that would eliminate dangerous

spin tendencies exhibited by this type of airplane in service. The effects on steady spins and on recoveries of changing the loading, enlarging the fin areas, changing the elevator plan form, and raising the horizontal surfaces, were determined. Five fin sizes, two elevator plan forms, and three vertical positions of the horizontal surfaces were tested with four airplane loadings corresponding to different service conditions for which the airplane may be used. The effect on recovery of various methods of control manipulation and the immediate effect on various spin parameters of deflecting one or more of the controls from the normal setting were determined. The flight results were analyzed and compared with the results of spinning-balance tests of a model of the subject airplane.

The variations of loading did not materially affect the steady spin or the recovery. Increasing the fin area progressively improved ease of recovery but had little effect on the steady spin; and modifying the elevator to diminish interference had little beneficial effect. Raising the horizontal surfaces gave the most pronounced beneficial effect on recovery, making possible recoveries in less than one turn. The alterations made to the horizontal and vertical surfaces for the tests did not introduce undesirable flying characteristics. Flight tests and model tests were in general agreement but there were apparent discrepancies in certain details, particularly in regard to the comparative merits of several ways of manipulating the controls for recovery.

Dangerous spins were encountered during the tests as a result of displacing the controls, particularly the rudder, away from the usual position for the normal spin. Observations of the manner in which these dangerous spins were started indicated the probable conditions under which trouble had been experienced with this airplane in service.

PRINCIPLES OF METALLOGRAPHY. By Robert S. Williams, Ph.D. and Victor O. Homerberg, Sc.D., Massachusetts Institute of Technology. Third Edition, 313 pages, 14 × 20.3 cm. 302 figures. McGraw-Hill Book Co., Inc., New York, 1935. Price $3.50.

The first edition of this text appeared in 1919 and the second in 1928. The text has been rewritten and rearranged in large measure with addition of considerable material on aluminum alloys and the modern steel alloys. Professor A. V. deForrest has contributed the section on magnetic testing, M. Cohen has rewritten the section on X-ray testing and W. Zieler has revised the section on optics.

The authors have succeeded very satisfactorily in their design of presenting a fairly comprehensive but not advanced textbook on metallography. For the more specialized information reference must be made to more advanced works. The large number of photomicrographs and diagrams, both generally well done, illuminate the text very satisfactorily. Fifty pages are given to laboratory methods and the appendix gives an outline of a brief laboratory course. An extended list of books and journals dealing with metallurgy or metallography, a table of common and industrial alloys, tables of etching solutions and other tables of specialized information are included in the appendix.

The volume gives every evidence of being a useful not too difficult text especially adapted for the general reader and non-professional metallographer. It

shares the excellent qualities of book manufacture of the International Chemical Series of which it is a member.

LESLIE R. BACON.

COMMUNICATION NETWORKS, Vol. II, The Classical Theory of Lone Lines, Filters and Related Networks, by Ernst A. Guillemin, Ph.D. 587 pages, tables, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd., 1935. Price $7.50.

The principles of transmission line engineering whether for power or communication are too general in nature to remain confined to one field of application. Recently these principles began to make their appearance in the treatment of power problems as well as in communication. This volume presents a thorough treatment of the transmission line as a communication facility, this viewpoint being chosen, according to the author, because it affords at present a more suitable vehicle for illustrating the fundamental principles.

The book is a complete and, what may be termed, vigorous text. It starts with a discussion on the engineering formulation of the long line problem to acquaint the reader with the basis upon which the engineering considerations of the long-line problem rest so that he will have a better appreciation of their limitations, and to arouse his interest in pursuing this problem from a more rigorous angle later when he shall have become thoroughly familiar with the elementary treatment. The reader is then led through treatments on the characteristics of four terminal networks, artificial and lump-loaded lines, to the non-dissipative uniform ladder structure. Here is considered the structure's steady-state behavior when excited at one end by means of a harmonic generator with an internal impedance, while the far end is terminated with another impedance.

Of particular interest are the chapters on filters—their theory, design and behavior. The conventional filter theory utilizing the properties of the uniform ladder structure as a point of departure is first taken up after which, methods of design are discussed. There is brought out a treatment on filter design methods based upon the lattice structure as a means of avoiding lack of flexibility of previously discussed methods. Under a chapter headed "The Transient Behavior of Filters" the author introduces the Fourier integral, an outgrowth of the Fourier series. This method, it is stated, points out the requirements for ideal transmission and the roles which are played by the amplitude and phase characteristics. It enables the establishment of criteria for allowable departures from the ideal in terms of allowable departures in the faithfulness of reproduction.

The book is concluded by two parts, the first on simulative and corrective networks, the second on the transient behavior of long lines covering the solution in terms of normal functions, the expansion problem and the properly terminated line.

At the end of each chapter of the book there are exercises. An examination of some discloses that great care was practiced in their formulation in order to thoroughly impress the student with the work covered. The author has let nothing interfere to make the book as complete and as clear as possible. Every assistance is given to stimulate and maintain interest for those students educationally equipped to persue the subject. The book is of great value to transmission line engineers.

R. H. OPPERMANN.

ELECTRICAL MEASUREMENTS IN PRINCIPLE AND PRACTICE, by H. Cobden Turner and E. H. W. Banner. 354 pages, illustrations, tables, 14 × 22 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $4.50.

This is a book for those engineers and others who are concerned with the application of electrical measuring devices to specific purposes, but who do not require a text-book involving such mathematical theories of operation as are essential to the student and research worker. The first thing that is apparent upon examination of the book is its conveniently simple construction—the division of subject matter so that understanding and reference are facilitated. It is divided into five parts under the headings of units and standards; instruments as tools of measurement wherein there is treated electromagnetic, electrostatic and thermal instruments, testing sets, galvanometers, oscillographs and potentiometers to the extent that there are shown the characteristics of use to the user including enough design data so that the possibilities and limitations may be realized; measurement of electrical quantities such as current, voltage, power energy and measurements at audio and radio frequencies; measurement of electrical properties of apparatus discussing resistance, impedance, inductance, capacitance and magnetic measurements; indirect electrical measurements including temperature, light and speed, and miscellaneous measurements.

A very unusual part of the book is a series of three charts inserted as a frontispiece. The charts show at a glance, for voltage, current and resistance measurements, the type of instrument used for the measurement of various quantities of each and general remarks regarding the accuracy of each and other information.

A glossary of terms used in instruments and measurement, and a subject index complete the book. The former is another unusual feature aiming at completeness of treatment that is obviously very useful when considering those to whom the book is primarily directed.

The book is profusely illustrated with photographs of the various instruments and with diagrams of connections. The treatment is adequate, clear and concise. It should be a very valuable addition to the library of practicing engineers as well as to the electrical tester.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

The Earth Among the Stars, by Marian Lockwood and Arthur L. Draper. 91 pages, illustrations, 14.5 × 19.5 cms. New York, Basic Books, Inc. n.d. Price thirty-five cents.

Handbook of the Heavens, edited by Hubert J. Bernhard, Dorothy A. Bennett and Hugh S. Rice. 131 pages, tables, illustrations, 15 × 23.5 cms. New York, McGraw-Hill Book Company, Inc. Price $1.00.

Electrical Measurements in Principle and Practice, by H. Cobden Turner and E. H. W. Banner. 353 pages, illustrations, 14 × 22 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $4.50.

Praktische Physik zum Gebrauch für Unterricht, Forschung und Technik, von F. Kohlrausch, Siebzehnte Vollständig Neu Bearbeitete Auflage. 958

pages, tables, illustrations, 16 × 23.5 cms. Leipzig, B. G. Teubner, 1935. Price 32 marks.

Physics, by Erich Hausmann and Edgar P. Slack, 775 pages, tables, illustrations, 14.5 × 22 cms. New York, D. Van Nostrand Company, Inc. n.d. Price $4.00.

Man the Universe-Builder, by Richard E. Lee. 441 pages, illustrations, 14.5 × 22 cms. Baltimore, The Williams & Wilkins Company, 1935. Price $3.00.

Communication Networks, Vol. II, *The Classical Theory of Long Lines, Filters and Related Networks*, by Ernst A. Guillemin, Ph.D. 587 pages, illustrations, 14.5 × 23 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. 1935. Price $7.50.

Life and Experiences of a Bengali Chemist, Vol. II, by Prafulla Chandra Ray. 469 pages, 14.5 × 22.5 cms. Calcutta, Chuckervertty, Chatterjee & Co., Ltd. London, Kegan Paul, Trench, Trubner & Co., Ltd. 1935.

Mathematical and Geometrical Demonstrations, by Carl Theodore Heisel, second edition. 330 pages, tables, illustrations, 17.5 × 26.5 cms. Cleveland, Author, 1934.

Canada Dominion Bureau of Statistics. Live Stock and Animal Products Statistics, 1934. 97 pages, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price twenty-five cents.

Versuchsgrubengesellschaft, Bericht Heft 7, Untersuchungen über den Verlauf von Schlagwetter- und Kohlenstaubexplosionen. I. Die angewandten Verfahren und Geräte, von H. Schultze-Rhonhof und Karl Fischer. 56 pages, illustrations, 16 × 24 cms. Gelsenkirchen, Carl Bertenburg, 1935.

National Advisory Committee for Aeronautics, Technical Notes, No. 543, The Compressibility Burble, by John Stack, 9 pages, figures, 20 × 26 cms. Washington, Committee, 1935.

Bell Telephone Laboratories, Monographs: B-875, An Electron Diffraction Camera, by L. H. Germer, 8 pages. B-879, Methods for Resonant Circuit Response and Impedance Calculations, by H. T. Budenbom. 19 pages, illustrations. 2 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1935.

CURRENT TOPICS.

Rubber Belting now Produced by Continuous Vulcanization.—(*Chem. and Met. Engr'g.*, Vol. 42, No. 9.) An improvement in the production of rubber power-transmission belting by a new continuous vulcanization process has recently been reported by the Boston Woven Hose and Rubber Co. The new process substitutes a continuous rotary vulcanizer for the intermittent flat-bed vulcanizing press that has heretofore been universally employed for the purpose, with, it is stated, important advances in product quality. Rubber transmission belting consists of several plies of cotton duck impregnated with a rubber compound, generally skimcoated with a thin layer of rubber, and then layed one on the other. Uniformity is produced both because of the continuous nature of the vulcanization and because the pressure, being applied flexibly, is constant regardless of variations in belt thickness. In addition, complete uniformity of tension during vulcanization is attained without dependence on the human factor.

R. H. O.

Southern Pines and Sabbatical Years.—From the Forest Service Bureau of the U. S. Department of Agriculture comes word that a bumper pine seed crop, which occurs about every seven years, is maturing in the South. Coupled with this announcement is a warning of greater losses to pine-tree seedlings if there is the customary burning of forest pastures in the southern pine regions this year.

Many of the great even-aged stands of longleaf slash, loblolly, and shortleaf, the four principal species of southern pine, can be traced back to a year of extraordinary seed production. What causes this heavy seed crop at regular intervals, generation after generation, is still a mystery but the trees seemingly store up a supply of food beforehand in preparation for these periodical propagative efforts. Also, it has been observed that some trees when injured or dying will produce a heavy seed crop—apparently in a final effort to continue their kind—although the season may not be the one for heavy seed production.

C.

Dinitrophenol—A Slim Chance.—According to W. G. CAMPBELL, Chief of the Federal Food and Drug Administration, those

who seek to become slim through the use of dinitrophenol have even a slimmer chance of escaping all the many damaging effects this drug exerts upon the human body. One of the more serious ailments caused by dinitrophenol is that of eye cataracts. These are observed to develop with a rapidity and malignancy hitherto unknown and result in total blindness within a comparatively short time. This drug also may produce acute poisoning, the symptoms of which are nausea, stomach and intestinal distress, sweating, flushed skin, high fever, rapid breathing and muscular rigor followed by death. Damage to the liver, kidneys, heart and sensory nerves also occurs. Dinitrophenol produces agranulocytosis, a blood disorder also noted in cases of poisoning with amidopyrine, a common ingredient of medicine for the relief of pain.

C.

A Sensitive Anemometer.—A new type of anemometer, especially designed for measuring slow air movements such as are present in refrigerator cars, has been developed by the U. S. Bureaus of Agricultural Engineering and of Plant Industry. Operation of the instrument depends on the cooling of a heated wire when exposed to air currents and is small enough to be placed under the floor rack of a car. It may be read from the outside without disturbing conditions inside.

Previous to the development of anemometer, observations of air velocities in cars were confined largely to smoke tests. Puffs of dense smoke were released at certain points in cars and observations were made of how long it took the smoke to travel to other points. The general direction of air movements could be followed and some idea of velocities of currents were obtained in this way. Difficulty of access to many positions in cars and diffusion of the smoke limited the usefulness of this method.

C.

The Copper Cottage—The Patina Palace.—*The Engineering and Mining Journal* for September, 1935, announces the plans of a well-known copper company to encourage the building of moderately priced houses out of this metal. The first dwelling of its kind has just been completed at Bethesda, a suburb of Washington, D. C. Although the frame is of structural steel, the outside walls, roof and roofing accessories, in addition to plumbing and heating lines, hardware, and many other things within the house are of copper or copper alloys, which protect against deterioration.

The outside walls consist of heavy copper plates backed by half-inch composition board, which adds stability to the sheets and

minimizes metallic noises when the plates are struck. The sheets of copper are held together by specially designed bronze holding strips, which provide for horizonal and vertical expansion and make the building weather and insect proof. The roof is covered with regular 16-ounce sheet copper over a wood deck, and heat and cold insulation is provided for by a 4-inch thickness of spun glass inside the walls and roof. Inside walls of the house are plastered on metal lath and the space between is also filled with spun glass. Such a wall of about six inches total thickness is equivalent to approximately eight feet of solid masonry in keeping out heat or cold.

C.

Vitamin C and Cataracts.—Almost coincident with the Bureau of Food and Drug Administration's warning that dinitrophenal will cause blindness through the rapid growth of cataracts, *Science* (Sept. 6, 1935) publishes a report by E. M. JOSEPHSON indicating a successful treatment of the toxic effects of this drug using ascorbic acid, vitamin C. The response of the very rapidly progressive dinitrophenol cataracts to ascorbic acid therapy was surprisingly rapid. Other toxic symptoms such as the typical neuritis also responded promptly to vitamin C administration.

C.

Cast Iron Plate Roofing—A New Product Of The Foundry.—(*Iron Age*, Vol. 136, No. 11.) That cast iron has ideal qualities as a roofing material is quite evident. According to C. ALBERT WETTENGEL of American Zinc, Lead and Smelting Co., St. Louis, who has given considerable time to research on this subject, the oldest existing cast iron roofing seems to be that on the famous Chinese temple at Tai Shan. Three buildings forming this group, constructed about 500 years ago, are provided with cast iron roofs and are in excellent condition. Also the great dome of the National Capital at Washington was provided with cast iron roof plates in 1870 and there has been no maintenance cost since. As a recent departure in its business, the United States Pipe and FoundryCo., Burlington, N. J., has designed and perfected a standardized cast iron roofing material for industrial buildings. It is recommended for installations with roof slopes of not less than 4 in. in 12 in. Essentially there are two main units—a standard cast iron plate and a cap plate. The former is a single casting of 3/16 in. thickness 52 in. long and 24 in. wide. This rests on the roof purlins and is provided with flanges along the longitudinal sides to prevent joint leakage and impart strength to the casting. The cast iron cap is semi-cylindrical

in shape, the same length as the roof plate, and is secured over the flanges of the roof plate. Only a few accessories are required for this new type of cast iron roofing. This is the first cast iron roof to be manufactured and sold on a commercial basis. A number of installations have already been made.

R. H. O.

An Oil Manometer.—G. H. VAN HENGEL and J. D. STARKWEATHER (*Mech. Engineering*, Vol. 57, No. 10.) A new kind of instrument is described for use in measuring the absolute pressure of steam in condensers. For the past two years the authors have been using four oil manometers of a type which is new in power plant testing practice although well known in certain fields of research. It is similar in principle to a gage developed by K. C. D. Hickman. Essentially a U tube manometer, the instrument contains a non-volatile organic liquid (Di-n-butyl phthalate) in place of mercury. A high vacuum in the reference leg is maintained by a condensation pump connected in series with a high-vacuum mechanical pump. For power plant testing, the use of a high vacuum pumping system might well be impracticable but for the development of the miniature condensation pump which is electrically heated by means of a 110 V. 80 watt, non-automatic cigar lighter connected in series with a 110 V. 150 watt bulb. The pump is made of glass and operated with di-n-butyl phthalate. Its air cooled condenser is built integral with the gage. Proper operation of the condensation pump is evident to the eye. The liquid boils without "bumping" and a film of condensate from the condenser is to be seen running down the wall of the pump.

The authors describe the installation and operation of the instrument and give an appendix containing density figures for di-n-butyl phthalate and other properties. This gage is of high sensitivity, giving a deflection about thirteen times that of mercury. An additional advantage of the large deflection is that capillary errors, of much moment when mercury is used, become a negligible percentage of the total deflection.

R. H. O.

The Florida Ship Canal. W. F. COACHMAN, JR. (*Manufacturers Record*, Vol. CIV, No. 10.)—This is the greatest canal project undertaken by our government since the Panama Canal. Connecting the Atlantic Ocean with the Gulf of Mexico, it will be possible for barges and small craft to travel from Boston to Mexico on a protected inland water route. This sea level canal is to be accomplished by deepening and straightening three natural rivers—the St. Johns,

Oklawaha and Withlacoochee—and by means of an artificial cut of 28 miles to connect the Oklawaha and the Withlacoochee Rivers. Ships will enter from the Atlantic side at the mouth of the St. John's River near Jacksonville, pass Palatka, thence just south of Ocala and Dunnellon, and into the Gulf of Mexico at Port Inglis. It is estimated that 26,000 acres of land must be cleared; 569,675,000 cubic yards of earth and rock excavated; four spillway dams constructed, and 10 highway and railroad bridges built before the canal can be opened. The distance from the lightship on the Atlantic side to the lightship on the Gulf side is 189 miles. The depth will be 30 feet usable draft when opened to navigation in 1941.

R. H. O.

Spheroidal Tanks Used at New Michigan Water Terminal. JOHN W. THOMPSON. (*National Petroleum News*, Vol. XXVII, No. 39.)—One of the many marine terminals on the Michigan shore line is the huge development at Muskegon on Lake Michigan by the Socony-Vacuum Oil Co. From here shipments of gasoline from barges can be economically distributed by short truck routes to the entire state. Two Horton spheroids, said to be the first ever constructed in Michigan, are located here. One of these has a capacity of 80,000 and the other 60,000 barrels of the company's regular gasoline. Another of the former size is being constructed. The tanks are designed to operate with a working pressure of 2½ lb. per sq. in. which materially reduces evaporation losses by permitting a pressure to build up inside of the tank instead of venting as the temperature increases. Two pressure vacuum vents keep the tank sealed until the internal pressure goes above the amount for which the structure is designed. One is set at 2½ lbs. and the other, serving as a safety measure, is set at 3 lbs. pressure. The pressure vacuum vent is of a special type, a liquid seal type, in which the pressure within the tank pushes a column of liquid, glycerine and water, up through a vertical pipe into a float box, where it lifts a float and opens the pressure relief valve. The vacuum vent consists of an inverted metal cup, which raises and admits air upon the formation of a very slight vacuum. Glycerine is used with water in the vent to prevent freezing. In an effort to reduce evaporation losses to a minimum, all loading operations, both tank truck and tank car, are done with a submerged aluminum fill-pipe which goes to the bottom of the tank.

R. H. O.

A Dilatometer for Measuring the Expansion of Metals. (*Power Plant Engineering*, Vol. XXXIX, No. 10.)—The laboratory of the

General Electric Co. contains an instrument known as a dilatometer which measures and records, in ten-thousandths of an inch, the expansion and contraction of metals as they are heated and cooled. Built from specifications of the U. S. Bureau of Standards, it consists of a small cylindrical furnace surrounding a quartz tube. A round core of about the size of a thick pencil and made of the metal to be tested is placed within the tube, which is then electrically heated up to 1800 deg. F. On top of the specimen is placed another smaller quartz tube, sealed at both ends, to transmit the dilation of the specimen to a dial gage. The gage is connected by an Invar clamp to the outside quartz tube and can be read to 0.0001 inch. This instrument determines accurately such irregularities as occur when metals expand in spurts and when they may contract in spite of increased heat. Such information is very valuable in welding, brazing or heat treating.

R. H. O.

Air Conditioning and Refrigeration on the "Normandie." G. VINCENT BUTLER. (*Refrigerating Engineering*, Vol. 30, No. 4.)—Nothing in recent marine development challenges the imagination as does the S. S. "Normandie." This 1029-foot ship can operate backward or forward with equal power and she is as thoroughly fireproofed as research can make her, with walls of all cabins formed by sheets of duralumin between layers of asbestos and covered with fireproof paint. There is not a visible lighting bulb in the entire ship; illumination is provided by luminous cornices of molded glass, bulbs recessed in sunken panels, etc. Her 300-ft. dining salon is located in the center of the ship—a radical departure in ship construction made possible by air-conditioning equipment to provide, continuously, a sufficient volume of cleansed air, properly distributed and at the desired temperature and proper moisture content. The installation constitutes the largest air-conditioning system installed aboard any ship. The volume of the hall is 233,000 ft.^{3} with 11,500 ft.^{2} of floor space. Of the 58,000 ft.^{3} of air introduced per minute, 42,000 ft.^{3} are normally withdrawn via return ducts and recirculated. Then the remaining 16,000 ft.^{3} passes into adjacent parts of the vessel, notably the kitchen, and an equal amount is made up from outside atmosphere. This design arrangement allows 15 air changes hourly in the hall and a complete outside air change every 15 minutes. The conditioned air is delivered horizontally and at low pressure into the upper part of the dining salon, successfully eliminating perceptible movements in the occupied zone. The refrigerating unit necessary for cooling the water supplied to the air washer is one 185-ton centrifugal compressor using methylene

chloride. The refrigeration unit constitutes a compact group comprising a compressor, condenser and evaporator.

R. H. O.

Death Light for Insects. (*Business Week*, Oct. 5, 1935.)—Prof. W. B. HERMS and his assistant, J. K. ELLSWORTH of the University of California, experimenting in their laboratory with the effect of colored light on insects, found that each type of pest has a "favorite color." Continued experiments indicated the color preferences of each kind of flying insect and the exact intensity which attracts it most effectively. The grape leafhopper for instance, nightmare of California's vineyardists, prefers pale blue. So does the artichoke plume moth. A device was worked out putting the discoveries to actual use in the fields. It consists of a wire cage 8 in. in diameter, the alternate wires being connected to the terminals of a transformer which supplies enough voltage to electrocute the insects. A luminescent tube is used as a lure and is suspended along the axis of the cage so that the insect will come in contact with the wires as it flies toward the light.

R. H. O.

Cotton-Fabric Reinforced Roads. W. K. BECKHAM AND W. H. MILLS. (*Engineering News Record*, Vol. 115 No. 14.)—For the purpose of developing additional use for the product that occupies so important a place in the agricultural and manufacturing activities of the state, the South Carolina highway department in 1926 began studies on cotton fabric as a reinforcement for bituminous surface treatment. To date this practice and use has reached a stage of high development. Eight practical experiments were made on roads using several kinds of fabric. Conclusions recommend for future work a fabric with warp ends from 12 to 17 per inch and fill ends from 12 to 17 per inch, weighing about 4.25 oz. per sq. yd. Based on results obtained on experiments conducted prior to 1935, it appears that cotton fabric used as a reinforcement in bituminous surface treatment reduces cracking, raveling and failures. When the fabric is properly embedded in bituminous material, it is well preserved. In one instance, fabric which has been down for nine years is still in good condition. The experimental sections constructed this year should give very valuable additional information, as a number of different methods of construction have been included.

R. H. O.

Telemetering Aids Operation of District Steam Distribution System.—T. E. PURCELL describes in *Heating, Piping and Air*

Conditioning, Vol. 7, No. 10, a modern installation which is a decided asset for good service provided by the Allegheny County Steam Heating Co., Pittsburgh. The district heating system consists of two modern plants having a combined capacity of about 1,200,000 lb. per hr. of steam and a smaller plant held in reserve. The distribution area comprises about one square mile and serves 242 customers. A distinctive feature is the return of about 80 per cent of the condensate through pipe lines paralleling the main steam lines.

In the telemetering installation an oscillating element operated at a uniform speed by a synchronous motor at the transmitter makes and breaks an electric telemetering circuit at time intervals proportional to the displacements to be transmitted. These displacements are actuated by either pressure, rate of flow, etc. The intermittent electric current thus transmitted operates a pair of electric clutches in the receiving instrument which also revolve at uniform speeds but in opposite directions by means of a local synchronous motor. The motion of these clutches through a limited arc is transmitted to the recording and indicating elements of the meter. Variations in strength of the transmitting electric current do not affect the accuracy of metering, since its only function is one of timing, and this is done by making use of relatively low voltage telephone circuits.

Fourteen long distance recorders are installed in order that all steam pressures be maintained reasonably constant. A particularly important instrument used in addition is the multi-point recorder which gives a continuous record of the contamination of the returning condensate.

R. H. O.

Removal from Solution of Minute Amounts of Gold and Silver.—WM. E. CALDWELL, Oregon State Agricultural College, speaking before the San Francisco American Chemical Society Convention described a method whereby as little as 1 part of gold in 4 billion and 1 part silver in 40 million can be successfully removed from the solution. Such quantitative recovery is accomplished by permitting to fall through the solution, a mercury-mercurous chloride residue, which residue is produced by reduction of mercuric chloride by powdered magnesium and acid. Assay of the residue permits the quantitative determination of gold and silver with an accuracy equivalent to the more general cupellation procedure. The removal of gold and silver from seawater is quite possible with such a method but not practical from the standpoint of present costs.

C.

Prevent Sunburn by Taking Iron.—At the recent San Francisco Meeting of the American Chemical Society L. EDER, Santa Barbara Clinic, reported that the routine administration of iron to the so-called "normal" infants and children resulted in greater tolerance to the sun and an absence of the frequent burning and blistering of the skin. Cases known to be sun-sensitive exhibited an increased tolerance to the ultra-violet rays after being placed on iron therapy. Improvement in general well-being, appetite and appearance also resulted.

The author is of the opinion that a hemoglobin test is not a sure way of determining the iron reserve of the body since the former maintains itself as long as there is any reserve upon which it may draw. When such reserve is depleted secondary anemia will occur.

C.

The Vitamin Content of Chow Mein.—During a series of studies on the nutritional value of some oriental foods, L. S. WEATHERBY AND S. MURRAY undertook to determine the vitamin content of chow mein by the usual method of feeding white rats. Vitamins A, B and D were found present in quantities sufficient to correct those pathological conditions caused by their respective deficiencies. A test to show the complete sufficiency of chow mein was conducted by feeding five rats a diet of that alone from weaning time until the animals were six months old. The rats showed no signs of any deficiency through the entire period. This showed not only the adequacy of the vitamin content, but also of the mineral and protein content of chow mein.

C.

Seven-Eighths Less Smoke.—JAMES F. POLLARD relates in *Power*, Vol. 79, No. 10, how the Lake Union plant of the Seattle Gas Company attacked the smoke problem by means of individual smoke alarm units on each of the boilers operated at the plant, as well as in the stack itself. The boiler plant consists of nine 1,500 sq. ft. h. r. t. boilers, eight of which are in double settings and one, single. They are mounted in two banks, one of five and one of four. Three boilers are arranged for oil firing. The balance are equipped with stokers for solid fuel, and tar is also used. By mounting a smoke alarm immediately above each boiler, it becomes possible to detect the exact source of the smoke at once, before a long column of smoke has reached the stack. A novel method was employed to protect the units from heat. The smoke alarm unit installed in the stack has a light source at one side of the stack and the photo-electronic cell on the opposite side. Both mountings have a small jet of

compressed air impinging on the glass surfaces to prevent accumulation of soot or cinders. In addition to an alarm relay, the stack installation is also coupled to a recording micro-ammeter. Thus a definite record is secured of the intensity as well as the duration of smoke emission. From the standpoint of boiler operation, the complete control set-up is proving most satisfactory, the smoke periods having been reduced from an average of 7.5 min. to an average of 0.94 min. per hour. Newspaper reports confirm the fact that the attitude of the community has been converted to one of friendliness and good-will.

R. H. O.

A New Type Waterless Gas Holder.—A brief illustrated description of the new type holder manufactured by the Bartlett Hayward Company of Baltimore is given in the *American Gas Journal*, Vol. 143, No. 4. It consists of a cylindrical shell, properly stiffened by vertical columns equally spaced about the circumference and regularly spaced horizontal stiffener galleries circumscribing the shell within which is provided a free moving or floating uniquely guided piston, and at the top of which is a suitably constructed roof with ample ventilating facilities to protect the inside. The piston guiding is accomplished by means of a vertical tubular steel post, located at the axis of the cylindrical shell. This post, passing through the center of a rigidly trussed and steel plate piston, extends from the holder bottom upon which it is supported up to the apex of the roof. It facilitates adequate and generous guiding for the piston in its vertical motion, permitting free circular movement of the piston whenever demanded.

R. H. O.

Air Conditioning Prevents Spread of Colds.—(*Heating and Ventilating*, Vol. XXXII, No. 10.) An air conditioned room at the University of California Hospital was used in studies undertaken by Doctors WM. J. KERR AND JOHN B. LAGEN to investigate the transmissibility of the common cold under controlled conditions of environment. This room, which provides bed space for 4 to 6 patients, is completely isolated from the outside atmosphere, being provided with its own air completely filtered and maintained at any temperature and humidity desired. It also contains an air lock, which permits ingress and egress with a minimum exchange of outside air. The room was maintained at a temperature of 70° to 71°, dry bulb, and 60° to 62°, wet bulb. The air flow is approximately 66 c.f.m. The experimental subjects were males between the ages of 21 and 40, who by history had 3 or more colds per year and

who had not had a cold in recent weeks. They were placed in the room in groups of 3 to 5 and allowed to remain between 5 and 8 days. At the end of this period an individual suffering from a common cold was brought in and allowed to remain 24 to 48 hours, the contact being such as exists normally in a home. After another 4 to 6 days, no common colds or any symptoms referable to a cold were observed in any of the 19 experimental subjects. Another experiment performed was the inoculation of the subjects with material obtained from individuals with fresh colds. In no instance did any of the nine subjects develop signs of a cold and there were no signs of conjunctival irritation.

R. H. O.

"Alusol" Welds Light Aluminum Alloys.—(*Industrial Gas*, Vol. 14, No. 4.) An engineer of Coventry, England, is reported to have perfected a process for welding various light aluminum alloys such as RR56 Duralumin, and others in this class. As is well known, attempts to produce such welds by ordinary means have been unsuccessful. The new welding medium is known as "Alusol" and may be used with aluminum castings, stampings, rolled sections, sheets or tubes, and fluxes readily at 392 deg. F. It is further stated that Alusol shows high resistance to corrosion, and is immune to aging. Owing to the high tensile strength and other mechanical properties of joints thus welded, the process should find wide application in the automotive and aeronautical industries

R. H. O.

New Thermometer Principle Devised.—(*Steel*, Vol. 97, No. 16.) Recently developed in Europe the new principle makes use of a bimetal strip which deflects in proportion to temperature change. It involves a unique method of winding the strip into a unit of concentric helical coils, so that the forces of deflection are additive, but the forces tending to cause distortion and friction are mutually counterbalanced within the coils. The new form of coil was first proposed as a result of mathematical analysis by Franz G. Block several years ago. A balanced unit consisting of concentric helices is the ideal form and because there was no equipment in existence on which such coils could be wound the scientist had to work out a new type of coil winding machine. Using the new form of coil, it is possible to construct rugged all-metal thermometers with an accuracy equal to or exceeding that of the ordinary spirit or mercury type, according to tests made in the laboratories of the German College of Science and Technology, Prague. Tiny thermometer elements less than ¼ inch in length, or large elements with sufficient torque to

move a pointer 6 or more feet in length can be constructed with the same general form of coil. Deflection sufficient to space out a narrow temperature range over a 360-degree circular scale is said to be obtained without encountering loss of accuracy.

R. H. O.

A High-Grade Aluminum Alloy Solder (*Science Service*).—According to the Department of Interior's Mineral Trade Notes, Great Britain, a new welding material, known as "Alusal," has been invented by an unnamed engineer of Coventry, Warwickshire, England. The method may be used to join aluminum in cast, rolled, sheet or tube form and fluxes freely at 200 degrees Centigrade (392° F.). Test pieces of such alloys as RR56 and Hiduminum tubing socketed together and joined with Aluson were only pulled apart at forces of twenty-six tons to the square inch, leaving the welded joint intact. The low temperatures required overcome the old trouble wherein attempts to weld aluminum in ordinary fashion destroyed the effects of the previous heat treatment. Alusol is claimed to withstand corrosion well and is unaffected by aging. Experiments are now underway to produce an all light alloy bicycle which will weigh but four and three-quarter pounds with only the wheels and seat removed.

The new process is analogous to soldering except that no flux is required. The aluminum alloy surfaces are first cleaned with special emphasis on the removal of oil, and the parts placed in a heating device. After each part has reached the required temperature, the Alusol is rubbed on carefully over the surface with a steel scraper, the pieces brought together, heated again and finally allowed to cool. This method also makes possible the joining of aluminum tubing to steel provided the latter is first tinned with a coat of soft solder. A joint of such character is said to withstand a pull of six tons per square inch.

C.

A House Cheaper than the Cheap Houses.—As an outcome of providing housing facilities at CCC camps MAJOR-GENERAL MOSELEY in the Fourth Army Area has found that modern family housing can be provided at a cost of only a few hundred dollars a house. During this year some 7,000 factory-made (prefabricated) lumber houses have been erected and found to meet ideally the requirements for sanitary, comfortable and presentable dwellings at small cost.

These prefabricated CCC houses are 20 × 20 feet, contain 34 factory-made panel units for floors, walls and roofs and 42 separate

pieces of lumber. Six men can easily erect a 20-foot, one-room bungalow in one day. Two men can lift any panel and with the aid of simple tackle can put even the roof sections in place. The demountable features of the structures are something new and render it perfectly feasible to transfer these dwellings from one site to another.

C.

Down the Molasses Road. (*I. & E. C. News Edition*, 13, 374).—A communication from K. R. NATARAJAN says that the Government of Mysore, India, through the Public Works Department, has been making good use of the molasses as road material. About 50 miles of road have been coated with molasses and are reported to be standing up in an excellent manner.

Here in America tests are being conducted on a road laid with salt. What next?

C.

Identification of the Lindbergh Ladder Nails.—Much has been written and heard about the wood in the Lindbergh ladder. But practically nothing has been said about the 44 nails that held it together. Yet these nails were identified with uncanny positiveness through the research of Stanley R. Keith, Metallurgical Engineer of Montclair, N. J., and Steel Technologist for the State in the Hauptmann trial. Mr. Keith, with the consent of Attorney General Wilentz, presents, in *Iron Age*, Vol. 136, No. 16, a resumé of the technological phase of the investigation of the nails in the ladder used in the kidnapping of the Lindbergh baby.

Starting from the fact that there were marketed during the previous year, 1931, almost 8 million kegs of wire nails, of which 25 per cent. were of the type and size found in the ladder, it was found that the ladder nails observed bore the letter P on the obverse side directly below the head and just above the grips. This significance as a trade mark and the steel being synonymous with Penna., especially Pittsburgh, led to the mill of the Pittsburgh Steel Co. at Monessen, Pa. This plant produced approximately 10 per cent. of these nails in 1931, narrowing the field from 2,000,000 kegs to 200,000 kegs. While all these ladder nails were similar with respect to the letter P, they fell systematically within 8 characteristic grip mark types, as the first sub-classification, viz.; E S T V A U G H. This was taken as a basic starting point.

Among Hauptmann's personal effects was a nail keg stamped with the same die as used at Monessen. A painstaking examination and classification, one by one, of these keg nails was made with

recorded results. They were found to be identical in the minutest detail, type for type, with those of the ladder group. Further research on the other personal effects taken from Hauptmann's overalls and from his garage coincided. Finally, the keg was logically taken as the legitimate source of supply for Hauptmann's nail demands, and without reference to the ladder group for the present, all other nails were figuratively returned to their known original keg, and the resultant numerical strength thereby attained made the basis for further extended analysis of their common 8 die-type status, into coil entities as the ultimate sub-division of their unit characteristics, and for the more subtle group characteristics which ensue. This required remarkable technique and ingenuity. The inescapable conclusion was reached that the ladder nails hail from the same technological lot as that of the contents of the keg.

The sudden and unexpected collapse of the defense alibi testimony so influenced the subsequent course of the State's presentation of this evidence, which was being withheld as the final surprise blow, as to involve its final omission altogether. R. H. O.

"All one can usually see as he goes through a research laboratory are the tools and the machinery of research."—T. A. Boyd, "Research."

Effect of Insulation on the Surface Temperatures of the Contents of Galvanized Corrugated-Iron Sheathed Buildings.—D. G. WILLIAMS (*Mech. Engineering*, Vol. 57, No. 11). This is a paper contributed by the Process Industries Division. It describes and gives results of an investigation on two buildings 40 ft. wide, 80 ft. long and 10 ft. high to the eaves inside, located in eastern Pennsylvania approximately 40° 40′ N. latitude. Tests were made in the summer from which it was concluded that roof and wall sheathings may absorb solar heat rays sufficient to heat the sheathing to temperatures higher than outside air temperatures; exposed surfaces of contents of an unheated building may have temperatures higher than the temperature of the atmosphere within or without the building due to the effect of heat radiated from the heated sheathing of the building; exposed surface temperatures of contents can be reduced by using building sheathing materials with higher reflective surfaces, both inside and outside; the greatest reduction can apparently be obtained by installing insulating linings on the building sheathing; painting the upper, more or less rough, black roof surface with aluminum paint reduced the temperature of exposed contents surfaces by approximately 5° F.; double-pitched or ridge-roof type of building construction appears to allow for the least

total amount of solar heat absorption by the external sheathing; the orientation of a building so that the long sides face north and south appears to allow for less total solar heat absorption.

R. H. O.

"If each one of us should do a little research of his own when occasion demands, we would not all be so dead sure of a number of things that are not so."—T. A. Boyd, "Research."

Not All Heat in Chili Peppers.—Nutritionists are no longer puzzled as to the source of Vitamin A in the Mexican diet. According to the Bureau of Home Economics preliminary tests indicate that the Vitamin A content of air-dry chili pepper is very high—two to three times that of a good grade butter. C.

"Sir Humphry Davy, speaking of Benjamin Franklin said, 'Franklin has in no instance exhibited that false dignity, by which philosophy is kept aloof from common applications; and he has sought rather to make her a useful inmate and servant in the common habitations of men, than to preserve her merely as an object of adoration in temples and palaces.'"—T. A. Boyd, 'Research."

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Wonderland of Science NOTES

DECEMBER, 1935

BEN FRANKLIN MEMBERS.

This issue of the JOURNAL will appear in the midst of a campaign for new members of the Institute. No concerted effort for public support has been made since the Institute moved to its new location and opened the exhibits and planetarium to public view. By this time also, a million visitors will have been entertained and instructed within the walls of this Science Center. Now that a considerable portion of the public has had an opportunity to judge of the value of the Institute to the community, it is felt that a generous response will be made. The many benefits obtained through membership make this form of community aid doubly attractive.

Though all classes of membership are included, especial effort will be directed toward the enrollment of Ben Franklin members (formerly museum members). This is an inexpensive form of membership designed for the general public who, without any particular scientific training, may wish to have unlimited access to the exhibits and the planetarium, and other advantages of membership. Coming at this season, it is hoped that many members and others will take advantage of the opportunity to make Christmas gifts of memberships, especially for students. An attractive Christmas card has been designed to notify the recipient.

Ben Franklin members are admitted free to the Wonderland of Science and the Planetarium, at all times, and they will receive notice of special demonstrations, such as those mentioned on nearby pages. For students in school or college

who are over twelve and under twenty-five years of age, the cost of membership is $2.00, for others $5.00. Family Membership, including all the members of a single household, costs $10.00, and a membership card is sent to each individual. Checks should be drawn to the order of The Franklin Institute and addressed to the Parkway at Twentieth Street, Philadelphia, enclosing a list of the names and addresses of the recipients.

It is felt that in spite of the low price of admission, the possession of a membership encourages frequent and less hurried visits to the Institute, which are apt to be less tiring and more instructive and entertaining than occasional longer visits.

AN EVENING OF ENTERTAINMENT.

The Franklin Institute offers an evening of entertainment for the Junior Clubwomen of the Southeastern District of the State Federation of Women's Clubs and their friends, Wednesday evening, December 18th, at eight o'clock.

FRANKLIN INSTITUTE APPOINTS MARRINER ASSOCIATE DIRECTOR, HEAD MUSIC SECTION.

Appointment of Guy Marriner, pianist, composer and lecturer, as Associate Director in charge of the Music Section at The Franklin Institute was announced today by Henry Butler Allen, Director.

"The creation of the Music Section with Mr. Marriner as its directing head is another step forward in the Institute's program of greater service to its members and visitors," said Director Allen.

Mr. Marriner in his fortnightly lecture-recitals in The Franklin Institute has demonstrated powers of interpretation that have already merited the praise of music experts in Vienna, Berlin, Rome, London, Amsterdam, Cologne, New Zealand and Poland.

When interviewed on his appointment today Mr. Marriner stated: "It seems to me that the establishment of the Music Section at The Franklin Institute is the first recognition by a scientific institution that science and art are indispensable to

each other, for were it not for the contributions of science to art we would not be where we are today.

"Look at the instruments—piano, all forms of wood wind and brass and strings, the organ, the radio, the sound-reproducing instruments. No matter in which field you look you find science has made enormous contributions. Composers may have been ahead of their time, but it took the world of science to show what those composers did.

"The action of The Franklin Institute in this instance is an enormous and important step and it is grand to think that Philadelphia leads the way in this country. Our possibilities at the Institute are unlimited.

"It seems to me to be the beginning of a new epoch for art, for while we recognise the fact that scientific developments are going ahead in every part of the country, we can in Philadelphia actually bring them before the public to allow every man, woman and child, and what is more important, those children who are inventors in embryo, to see in operation and draw inspiration from the latest developments in the field of science."

LECTURE-RECITALS ON THE ORIGIN AND HISTORY OF MUSIC FOR THE GENERAL PUBLIC, BY GUY MARRINER, PIANIST AND COMPOSER, IN THE LECTURE HALL OF THE FRANKLIN INSTITUTE.

No. 5, December 8th:

Sixteenth century "Golden Age." Elizabethan school, Luther, Calvin, the chorale. English reformation. Valentini, Martini. *Theme and Variations* by Mozart, Beethoven, Brahms and Infante.

No. 6, December 22d:

Tudor instruments. Troubadours, meistersinger, folk song, ballad singers, carols. Bull, Pepusch, Couperin. *Sonatas* by Galuppi, Beethoven, Schumann. Carol singing.

No. 7, January 12th:

Monteverde. Opera, oratorio, Lully, Purcell. Violin makers and players. Chamber music. The Scarlattis. Lully, Purcell, Arne, Shield, Scarlatti, Rameau.

FRANKLIN INSTITUTE CREATES DEPARTMENT OF PUBLIC RELATIONS. APPOINTS WILLIAM A. A. CASTELLINI, PUBLIC RELATIONS COUNSELOR, AS DIRECTOR.

William A. A. Castellini, public relations counselor, formerly of the organization of Edward L. Bernays, New York, has been appointed Director of Public Relations of The Franklin Institute. This was announced today by Henry Butler Allen, Director of the Museum, who stated that the new department has just been created to increase public appreciation of the educational facilities offered by The Franklin Institute and to disseminate information concerning its program of activities.

Prior to joining Bernays' organization as liaison officer at the Philco Radio and Television Corporation, Mr. Castellini had been identified with many of Cincinnati's most important civic, business and philanthropic enterprises, such as the American Red Cross, the Community Chest, the Cincinnati Chamber of Commerce and the Hamilton County Republican Party.

RECENT ACQUISITIONS IN YOUR "WONDERLAND OF SCIENCE."

Model of the ship "Welcome." Loaned by the Welcome Society of Pennsylvania.

Model of clipper ship "Flying Cloud." Loaned by Charles T. Lownes, West Chester, Pa.

Reproductions of Historical Clock Escapements. Donated by the Elgin National Watch Co.

Exhibition of Original Cover Designs for "The Colophon." Loaned by the Pynson Press, N. Y.

Exhibit showing the effect of heat treatment upon the tensile strength of alloy-steel as applied to aircraft structure. Donated by the Metallurgical Laboratory, Inc., Philadelphia.

RADIO BROADCASTS.

Radio broadcasts in dialogue form are given, through the courtesy of Station WCAU, every Saturday evening, at 6:00 o'clock during December. These broadcasts come from the Lecture Hall of the Institute and are free to visitors to the Institute.

For subjects of the broadcasts see your daily newspapers.

SCIENCE CENTER FALL AND WINTER SCHEDULE:

"Wonderland of Science."

Hours.

Wednesday ..... 2 p.m. to 10 p.m.
Thursday ..... 2 p.m. to 10 p.m.
Friday ..... 2 p.m. to 10 p.m.
Saturday ..... 10 a.m. to 10 p.m.
Sunday ..... 2 p.m. to 10 p.m.

Holidays same as Saturdays

All the sections will be closed on Monday and Tuesday of each week in order to give our scientific staff sufficient time to arrange special demonstrations and to adjust all operable exhibits.

Planetarium Demonstrations.

(Lasting about 45 minutes)

Wednesday	3 p.m.			8:30 p.m.
Thursday	3 p.m.			8:30 p.m.
Friday	3 p.m.			8:30 p.m.
Saturday	12 noon	3 p.m.	4 p.m.	8:30 p.m.
Sunday	3 p.m.		4 p.m.	8:30 p.m.

Holidays same as Sundays

During New Year's Week the Wonderland of Science will be open from 2 p.m. to 10 p.m. on Mondays and Tuesdays, with planetarium demonstrations at 3 p.m. and 8:30 p.m.

EXHIBITION OF PRINTS BY THE SCHOOL CHILDREN OF PHILADELPHIA.

Grammar School and High School Grades.

The Graphic Arts Section announces an exhibition of original work in woodcuts and linoleum cuts executed by Grammar and High School students of Philadelphia, to be held in the Institute from January 2 to January 19, 1936.

Each school will be permitted to enter ten pieces of work which must be selected by the Instructor in charge of the Art Department of each school. Exhibits received to December 20th.

The Graphic Arts Section of the Institute will award a printed Certificate of Merit to the school submitting the best group of work.

A printed Certificate of Merit will be awarded to the student submitting the best piece of work.

The work will be judged prior to and the winners announced at the opening of the exhibition.

INTERESTING TALKS AND DEMONSTRATIONS: MOVIES.

"A Trip To The Moon," Hall of Astronomy.

"Things That Spin," Hall of Physics.

"Photo Electric Organ," Franklin Hall.

"Romance of Dyes," Hall of Chemistry (ends December 13th).

"Making of Perfumes," Hall of Chemistry (begins December 14th).

"The Autogiro—Its Development," Hall of Aviation (begins December 4th).

Demonstrations during afternoons.

THE FELS PLANETARIUM PROGRAM FOR 1935-36.

[Parkway Entrance.]

Demonstrations of the Planetarium, accompanied by explanatory talks, will be given as follows:

December ..... Architecture of the Universe.

"THE HEAVENS DECLARE"

Dramatic planetarium presentation of the "First Christmas"

Special Musical Program
Unusual Lighting Effects

(December 11th–24th)

1936

January ..... Evening Skies of Winter.
February ..... Time and Navigation.
March ..... The Calendar.
April ..... How Will the World End?
May ..... Eclipses.
June ..... Stars at the North Pole.
July ..... Evening Skies of Summer.
August ..... The Moon.
September ..... Seven Thousand Years Ago.

TIMES of DEMONSTRATIONS.

Lasting about 45 minutes.

Wednesday	3:00 p.m.			8:30 p.m.
Thursday	3:00 p.m.			8:30 p.m.
Friday	3:00 p.m.			8:30 p.m.
Saturday	12:00 m.	3:00 p.m.	4:00 p.m.	8:30 p.m.
Sunday	3:00 p.m.		4:00 p.m.	8:30 p.m.

Holiday schedule same as Sunday. Closed Mondays and Tuesdays. After the evening demonstration visit the Observatory, no extra charge.

During Christmas Week and New Year's Week there will be demonstrations in the Fels Planetarium at 3 p.m. and 8:30 p.m. on Mondays and Tuesdays. The planetarium will be closed on *Christmas Day*.

"THE MAKING OF PERFUMES."

Beginning December 11th, the Chemistry Section of The Franklin Institute will give interesting demonstrations of "The Making of Perfumes."

The demonstrations have been arranged through the courtesy of E. I. du Pont de Nemours Inc. and the Continental Distilling Co.

Following a brief historical sketch of the development of perfumes, we see in operation the fermentation of sugar to form alcohol, and a 12-plate fractionating column of the "bubble cap" type, made of glass, which is used in obtaining alcohol of high proof from the fermented liquor. Incidental to the production of alcohol we also see how a block of dry ice is produced from the carbon dioxide from the fermentation vats.

We also see the steam distillation of sandalwood to obtain oil of sandalwood. This is one of the most important processes used today in obtaining the essential oils from natural sources.

Following a discussion of synthetics made today we see how the perfumer blends the various natural oils and synthetics to give that delicious softness of odor which is so much appreciated by the fairer sex.

Two ounces of an expensive brand of French perfume will be prepared at each demonstration. The perfume may be sampled by those so inclined.

The demonstrations will be given daily from Wednesday through Sunday.

THE MAGIC CHRISTMAS TREE.

Words fail to describe the Christmas Tree which will greet the visitors to The Franklin Institute during the holiday season, for beginning the middle of December a work of delightful magic will charm the eye.

Young and old will be thrilled by the sight of a Christmas Tree such as they have never seen before.

GRAPHIC ARTS PRESENTS THREE EXHIBITIONS.

During the holiday season, the Graphic Arts Department of the Benjamin Franklin Memorial and The Franklin Institute has arranged a program of interesting exhibitions to be held in the Wonderland of Science.

"Wall Paper Design and Manufacture," an exhibit which includes many original designs by outstanding artists, will continue until January 1st.

"Modern Bookbindings of Distinction" will be shown on the First Floor. It will include many European as well as American examples of fine craftsmanship.

"Illuminated Manuscripts" from the John Frederick Lewis Collection will be shown through the courtesy of The Free Library, on the Second Floor, from December 11th until the 29th. Manuscripts from the ninth to fifteenth centuries, representing the work of Germany, France, The Netherlands, England, Spain and Italy, have been selected as especially appropriate for this season.

The 1935 Fifty Books of the Year Exhibition, selected and arranged by The American Institute of Graphic Arts, will be on view to visitors to The Wonderland of Science during the month of December.

These exhibitions are open to all visitors to the Wonderland of Science.